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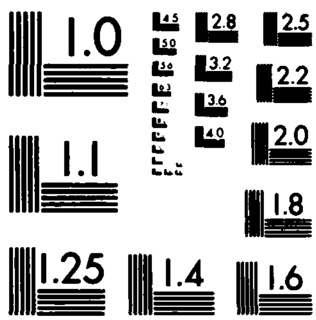

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TUG FORK RIVER BIG BEND CUTOFF BLAST MONITORING STUDY

by

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March 1983

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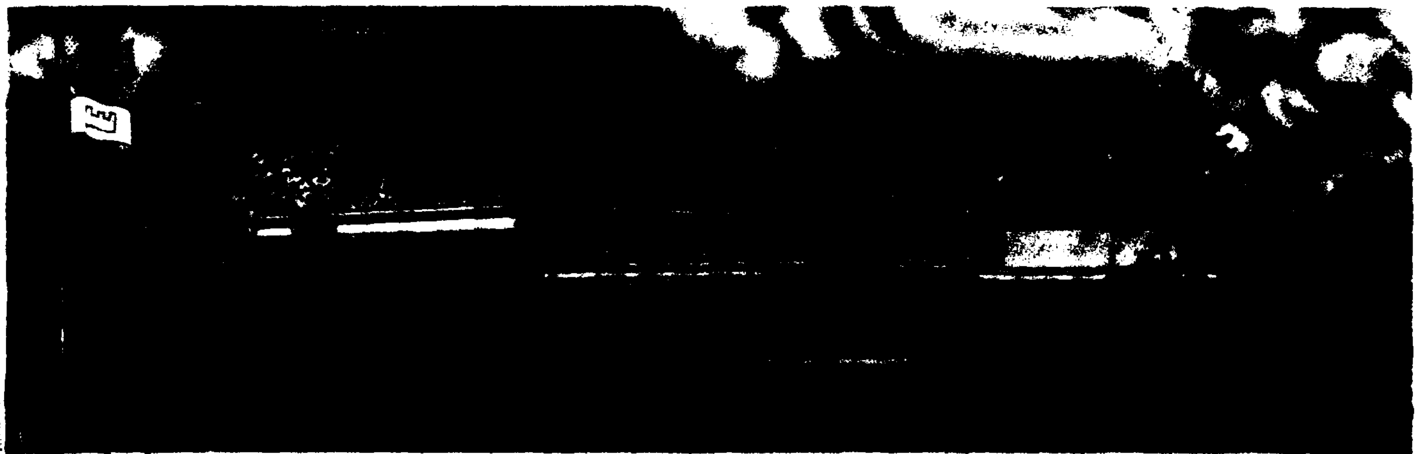

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This report documents the results of a blast vibration monitoring program conducted in the vicinity of the proposed Tug Fork River Big Bend Cutoff. Explosive and traffic (railroad and highway) induced vibration data were measured at selected sites in the vicinity of the proposed excavation. Analysis of these data shows that the railroad induced maximum peak particle velocities are one-tenth or less (≤0.2 in./sec) than the damage threshold for structures (2 in./sec) and one-fortieth or less than the damage threshold for unlined tunnels (8 in./sec). Dominant frequencies of the recorded data are in the (Continued)

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range 30 to 50 Hz. This frequency range dictates a minimum delay time of 30 msec.

PREFACE

This report describes a blast vibration monitoring study conducted at the Tug Fork Big Bend Cutoff near Matewan, W. Va. The study was initiated on 27 April 1981 under IOA E86-81-EG-07 for the Geology Section, Geotechnical Branch of the Huntington District, CE. Actual testing was postponed until April 1982 due to delays in gaining access to the site.

Mr. Charles E. Joachim of the Explosion Effects Division (EED), Structures Laboratory (SL), U. S. Army Engineer Waterways Experiment Station (WES) was the Project Engineer for this study and Mr. Joseph R. Curro, Earthquake Engineering and Geophysics Division (EEGD), Geotechnical Laboratory (GL), was responsible for the low level vibration monitoring program. The work was performed under the supervision of Mr. B. Mather, Chief, SL, Mr. W. F. Marcuson, III, Chief, GL, Mr. J. W. Brown, Chief, EED, and Mr. A. G. Franklin, Chief, EEGD. The field party included Mr. C. E. Joachim, SL; Messrs. J. R. Curro and D. E. Yule, GL; and Messrs. M. B. Savage, L. L. Smith, D. M. Galbreath and L. B. Smithhart, Instrumentation Services Division, WES. Data processing was performed by Mr. J. T. Brogan and Ms. D. W. McAlpin, EED.

Ms. Carol Spease of the Geology Section, Geotechnical Branch, Huntington District, was the Project Monitor for this work. Her outstanding assistance in the successful completion of this project is acknowledged.

COL Tilford C. Creel, CE, was Commander and Director of WES during the investigation. Mr. F. R. Brown was Technical Director.

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CONVERSION FACTORS, NON-SI TO SI (METRIC) UNITS OF MEASUREMENT

Non-SI units of measurements used in this report can be converted to SI (metric) units as follows:

Multiply	By	To Obtain
degrees	0.01745	radians
feet	0.3048	metres
feet per second per second	0.3048	metres per second per second
feet per pound (mass)$^{1/2}$	0.4526	metres per kilogram$^{1/2}$
inches per second	0.0254	metres per second
milliseconds per pound (mass)$^{1/2}$	1.4848	milliseconds per kilogram$^{1/2}$
pounds (mass)	0.4536	kilograms

TUG FORK RIVER BIG BEND CUTOFF
BLAST MONITORING STUDY

Objectives

1. The overall objective of this study is to establish safe blasting vibration criteria for the proposed Tug Fork River Big Bend Cutoff excavation. Specific objectives are to:

a. Measure train induced vibration levels at the lined and unlined railroad tunnels and selected typical structures.

b. Establish the maximum allowable peak particle velocity at each tunnel.

c. Estimate the peak particle velocity propagation equation for the excavation site.

d. Prepare a contour map showing allowable explosive charge weights per delay for the excavation.

Scope of Work

2. The work includes collection and analysis of explosive and traffic (railway and highway) induced vibration data near the proposed excavation. This included: (a) measurement of explosively induced vibration levels at nearby railroad tunnels and other selected sites; (b) recording train-generated vibration levels at railroad tunnels and other sites; and (c) measurement of highway vehicle-induced motions at selected locations.

Experimental Plan

3. Explosively induced motions were recorded from five (5) stemmed detonations. Particle velocity-time histories were recorded on rock surfaces close-in to the top of the charge hole (horizontal and vertical in a radial-vertical plane) and at seismic stations in soil and rock (horizontal-radial, vertical, and transverse components). Seismic motion

gages were located in the railroad tunnels (lined and unlined) and selected sites in the Sprigg and Hatfield Bottom communities. One self recording accelerograph was operated in the vicinity of an active coal mine (Long Pole Branch).

4. Shot hole and seismic recording station locations are shown in Figure 1. Gage location data for each shot are listed in Tables 1 through 5. Close-in particle velocity gage locations for each shot are shown to an expanded scale in Figures 2 through 6. Hyphenated gage station numbers indicate sites which were changed from one shot to the next. When one of these locations was used on a later shot the earlier designation is given. Seismic instrument locations are shown to an expanded scale in Figures 7 through 11.

5. Vibrations induced by railroad traffic were monitored with seismic transducers at selected sites. In addition highway traffic (coal truck, etc.) induced motions were recorded. These data analyses are presented in Appendix F.

Instrumentation

6. Close-in particle velocities were measured with Bell and Howell piezoelectric velocity transducers, Type 4-155-0111 and 4-155-0001. These gages are capable of measuring peak velocities of 200 and 100 in./sec, respectively. Both gage types have a flat frequency response from 1 to 2,000 Hz. Transducers were mounted in aluminum canisters (two gages each) of WES design and manufacture. Mounts were designed such that the two gage sensing axes were mutually perpendicular, one axis oriented perpendicular to the canister base.

7. Close-in gage canisters were bonded to exposed near planar rock surfaces. These surfaces were washed and dried prior to spreading a layer of five minute epoxy. The canister was placed on the epoxied surface with sufficient pressure to assure good bonding. During placement the sensing axis of the horizontal gage was alined with the charge hole. Since the rock surface to which the canisters were bonded was not a true horizontal surface the strike and dip of the canister top were measured

with a Brunton compass. These data are presented in Table 6. Note that while some gage locations were used more than once the differences in strike and dip are due to variations in the rock surfaces.

8. The close-in gages (Stations 1 through 5) and seismic stations 6 and 7 were hard wired into a recording van at the blasting site. Signals were processed through WES Model 103B DC amplifiers which have flat frequency response from DC to 10 kHz. The processed signals were recorded on a Sangamo Sabre 5 magnetic tape recorder (32 track) operated in the FM mode at a tape speed of 60 in./sec. The recorder has a flat frequency response of DC to 20 kHz when operated in this mode.

9. Self contained battery powered portable units, providing signal conditioning and recording capability for six data channels were used to record blast vibration data at Stations 8 through 17 and railway and highway vibrations at all locations. Motion transducer signals were passed through WES made DC amplifiers and recorded on an oscillograph using 3-5/8-in. wide direct-write oscillograph paper. Galvanometers used had a flat frequency response from DC to 60 Hz.

10. Velocity-type geophones were used to sense blast, and vehicular (train and highway) induced vibrations. Two geophone models were employed during the investigations because of sensitivity requirements. Three geophones, a triaxial array all the same type (one vertical and two horizontally oriented), were housed as a unit in a waterproof container. The L-4 (Mark Products) geophone with a sensitivity of 6 volts/in./sec and a natural frequency of 1.0 Hz was used to record vibration levels up to 0.5 in./sec. This transducer was used to measure blast and vehicular induced vibrations. MB (MB Electronics) transducers with a sensitivity of 96.3 millivolts/in./sec and a natural frequency of 2.5 Hz were used to record stronger vibrations up to about 2 in./sec from vehicular traffic. All geophones were damped to approximately 70 percent of critical to insure flat frequency response.

11. Geophone canisters were placed in intimate contact with the ground. Canisters at monitoring stations in soil were installed in shallow holes with the top surface at ground level. Soil was tamped around the canister to insure good coupling. Modeling clay was used to

provide coupling between the base and the media when the canisters were sited on rock or concrete.

12. A self recording accelerograph was installed near the entrance to an inactive coal mine in Long Pole Branch (Station 18). This unit recorded a triaxial array of accelerations on a strip of 35-mm photographic film. The recorder operated when subjected to accelerations equal to or greater than the preset trigger levels. These levels were 0.009 g's for Shots 1 and 2, and 0.0048 g's for Shots 3, 4, and 5.

Explosive Charges

13. All explosive work was done by Norwood Construction Co., Lexington, Kentucky, under contract to the Huntington District, Corps of Engineers. Austinite 40, a prilled ammonium nitrate material in 3-1/2 in. diameter by 28-1/2 in. long waterproof cartridges was the primary explosive for the blasting program. Austin 80 extra gelatin in 2 in. diameter by 8 in. long cartridges was used to boost each charge. Initiation was from the bottom of the hole using Dupont instant blasting caps inserted into the booster.

14. Charges were loaded into a 4-3/4 in. diameter drill hole. The loading sequence started with insertion of the blasting cap into a booster. Three sticks of Austin 80 extra gelatin were taped together for each booster except for Shot 1 where only one cartridge was used. The booster package was lowered to the bottom of the water filled hole. Next a rope was tied around an Austinite 40 cartridge which was gradually lowered into the hole as additional cartridges were added. Additional boosters were added to the charge train for Shots 4 and 5, after every 10th cartridge for Shot 4 and more often for Shot 5. The additional boosters ensured complete detonation of the explosive column. The heavy use of boosters for Shot 5 allowed the contractor to dispose of surplus material without creating an airblast nuisance. Explosive and charge hole data are presented in Table 7.

15. Prior to arming crushed limestone stemming was dumped into the shot hole. Arming procedures included hooking up the blasting cap leads

to the black and green conductors of a 4-conductor shielded cable. A second blasting cap wired in parallel was placed on the surface. A thin strand of wire wrapped around this blasting cap was attached to the red and white conductors of the shielded cable. This circuit provided zero time for the tape recorded data.

Data Reduction

16. The close-in data were recorded on magnetic tape in analog form. These raw data were digitized on an analog-to digital converter and the output recorded on another magnetic tape for later input to a data processing program. The digital tapes were processed through the computer to perform integration of the velocity-time histories. All data were then automatically plotted. Additional computer runs were required for baseline shifting, forcing the final velocity to zero at later times. The adjusted time-histories and their integrations are presented in Appendises A through E. Upward trace deflection represents upward (vertical gages) or outward (horizontal or radial gages) motion.

17. Oscillograph recordings of the seismic velocity data were converted to digital form on a curve follower digitizer. The converted data were then computer plotted with the three components recorded at each station placed on a page. These data are also presented in the Appendices (A through E).

Results and Discussion

18. Peak particle motion and duration of significant motion data are presented in Tables 8 through 12. The close-in peak particle velocity data listed here has been corrected for the tilt of the rock mounting surface using the strike, dip and bearing data from Table 6. The vertical correction multiplier is simply the inverse of the cosine of the dip angle. The horizontal correction multiplier is the cosine of the dip in the radial-vertical plane between the gage station and the shot hole. Since this bearing was not usually the direction of the

maximum dip this correction is in most cases less than the inverse of the vertical correction. The close-in time-histories presented in the Appendices (A through E) have not been corrected for tilt. No correction is necessary for the seismic stations as these gage installations were not tilted.

19. The R. D. Bailey experimental blasting program (Reference 1) is the basis for the Tug Fork blast monitoring study peak particle velocity predictions. The horizontal measurements were found to be significantly greater than either the vertical or transverse components. Therefore, a regression analysis of the horizontal data was conducted and the resulting equation was used as the peak velocity prediction equation for this study. The prediction equation was used for both horizontal and vertical peak motion predictions. The R. D. Bailey regression line is compared with measured peak vertical particle velocity data from the Tug Fork study in Figure 12. As shown here these data compare reasonably well with the regression line although the line has a slightly steeper slope than the data.

20. The measured peak vertical particle velocity data are presented again in Figure 13. A regression line, the result of analysis of the rock data, is presented for comparison. The 95 percent confidence band from a standard error of estimate calculation for the rock data is also shown. Note that most of the data (including most of the soil data) fall within the band.

21. The peak horizontal particle velocity data are presented in Figure 14. A regression line and 95 percent confidence band were also given for the rock data. Close-in peak horizontal particle velocities are significantly less than the vertical data at comparable distances. Farther out in the seismic region horizontal and vertical peak particle velocities are approximately equal.

22. Durations of the strong motions were measured from the time-histories presented in Appendices A through E. These data are presented in Tables 8 through 12 and plotted in scaled form in Figure 15. Although there is a great deal of scatter in this data, the regression analysis indicates an increase in scaled duration with greater scaled distance.

These data indicate that for larger charges there is a reduction in duration of strong motion.

23. Maximum existing peak particle velocity at the railroad tunnels induced by passing trains was 0.2 in./sec measured on the track ballast at the tunnel entrance. Inside the tunnels maximum peak particle velocities were 0.15 in./sec on rock in the unlined tunnel and 0.09 in./sec on concrete in the lined tunnel. These values are much lower than the peak allowable particle velocity in unlined tunnels. The explosive test data summarized in Reference 2 indicates the limit of rock spalling in unlined tunnels corresponds to a particle velocity of 18 in./sec. There were no reports of damage at particle velocities as low as 8 in./sec in Reference 3 where minor damage is defined as falling stones or formation of new cracks in tunnel walls. Hendron (Reference 4) recommends 10 in./sec.

24. Tunnel liners are designed to stabilize the opening and maintain the equilibrium of the rock mass by preventing movement of material into the excavated space. Therefore, lined tunnels can sustain larger transient motions than unlined openings. The data analyzed in Reference 2 indicates lined tunnels are undamaged by peak transient motions up to 60 in./sec. A lower value, 36 in./sec is suggested in Reference 3. Actually the peak particle velocity at the lined tunnel is controlled by the allowable peak particle velocity at the unlined tunnel since they are separated by a center to center distance of 72 ft.

25. The dominant frequencies seen in the seismic records range from 20 to 50 Hz in the seismic region with higher frequencies recorded close-in to the test blasts (Appendices A through E). This frequency range is common in soft rock sequences and is discussed by Langefors and Kihlstrom (Reference 5, p284). A minimum delay time of 30 msec is recommended for this condition. Where delays of less than 30 msec are desirable the sum of the charge weights for all charges within the 30 msec time period should not exceed the maximum single charge weight allowed at the site.

26. For example, a contractor wishes to excavate a bench with explosives. The complete operation requires 3000 lb of explosive

distributed in a 60 hole pattern (50 lb per hole). The bench is in a portion of the site restricted to 1000 lb maximum charge weight detonated per a 30 msec period. Msec delay blasting caps are available in 25 msec increments (25, 50, 75, 100, ...) and the contractor could elect to sequentially blast the bench using these caps. Since 25 msec is less than the specified period (30 msec) but greater than half that period (15 msec) the total allowable charge weight in 30 msec. Thus, if peak vibrations from all charges detonated in the 30 msec period were in phase and summed the velocity at a critical structure would not exceed the assumed safe value. Using this criteria the contractor can safely load all 60 holes blowing the bench sequentially in 10 hole increments 25 msec apart (at 0, 25, 50, 75, 100, and 125 msec).

27. The estimated propagation equation to be used for excavation blasting at the Tug Fork Big Bend Cutoff site is based on the peak vertical particle velocity data. The assumed empirical relation is the equation of the upper 95 percent confidence limit given in Figure 13. This line represents an effective upper bound for the measured data. The equation is:

$$V = 120.2\ W^{0.8435} R^{-1.687}$$

where:

V = peak particle velocity, in./sec

W = maximum charge weight per 30 msec delay, lb

R = slant distance, ft.

The analysis of variance for the peak vertical particle velocity versus scaled distance regression line is given in Table 13. Plots of charge weight per 30 msec delay versus distance for 8 in./sec (maximum allowable velocity at the unlined tunnel) and 2 in./sec (maximum allowable structural vibration) are presented in Figures 16 and 17 respectively.

28. The blasting contour map (charge weight per 30 msec delay) is presented in Figure 18. Assumed boundaries were the West Virginia bank of the Tug Fork River and the unlined Norfolk & Western Railroad tunnel. The allowable peak particle velocities were 2 in./sec on the river bank

and 8 in./sec at the tunnel. Horizontal distances were used in computing contours, a conservative practice. No assumptions of lift height or blasting patterns were made.

Conclusions

29. The maximum railroad induced peak particle velocities close-in to the railroad tracks are one-tenth or less ($\leq$0.2 in./sec) than the damage threshold for structures (2 in./sec). Peak motions necessary for tunnel damage are forty times greater than the railroad induced velocities.

30. The vertical blast induced peak particle velocities are greater than the horizontal component close-in. The difference diminishes with distance. The horizontal and vertical peak particle velocity data were essentially equal at the far field seismic recording stations. Therefore, the equation for the upper bound of the peak vertical velocity data is the best estimate of peak particle velocity for the proposed project.

31. The maximum charge weight per delay is a function of the frequency of the blast induced motion. Dominant frequencies of recorded motions were in the range 20 to 50 Hz. This frequency range dictates a minimum delay time of 30 msec. Shorter delays may be used with corresponding reduction in the charge weight per delay. The total charge weight per 30 msec should not exceed values shown on the blasting contour map (Figure 18).

Recommendations

32. Vibration monitoring from established sites is recommended for all blasting during the excavation sequence. Continuous monitoring will enable the contractor to change blasting methods, charge loadings etc., to take into account changes in site conditions.

Table 1

Shot 1 Gage Location Data

Station No.	Measurement	Slant Distance Charge cg to Gage ft	Remarks
1-1	UV,UH	40.3	Rock outcrop
1-2	UV,UH	42.7	Rock outcrop
1-3	UV,UH	44.0	Rock outcrop
1-4	UV,UH	54.6	Rock outcrop
5	UV,UH	66.6	Rock outcrop
6	UV,UR,UT	515	Rock outcrop
7	UV,UR,UT	943	Soil, Hatfield Bottom
8	UV,UR,UT	1482	Soil, lower terrace, Hatfield Bottom
9	UV,UR,UT	1579	Soil, upper terrace, Hatfield Bottom
10	UV,UR,UT	1916	Concrete slab, Full Gospel Church, Hatfield Bottom
11	UV,UR,UH	1918	Rock outcrop, Full Gospel Church, Hatfield Bottom
16	UV,UR,UH	2610	Concrete lined tunnel, Norfolk & Western Railroad
17	UV,UR,UH	2683	Rock unlined tunnel, Norfolk & Western Railroad
18	AV,AR,AT	6633	Long Pole Branch

Note: Gage type codes are: A = acceleration and U = velocity. Gage orientation codes are: V = vertical and H = horizontal. These codes are used in Tables 1 through 5 and 8 through 12.

Table 2

Shot 2 Gage Location Data

Station No.	Measurement	Slant Distance Charge cg to Gage ft	Remarks
1-1	UV,UH	47.0	Rock outcrop
2-2	UV,UH	31.3	Rock outcrop
1-3	UV,UH	58.4	Rock outcrop
1-4	UV,UH	73.2	Rock outcrop
5	UV,UH	88.7	Rock outcrop
6	UV,UR,UT	537	Rock outcrop
7	UV,UR,UT	970	Soil, Hatfield Bottom
10	UV,UR,UT	1948	Concrete slab, Full Gospel Church, Hatfield Bottom
11	UV,UR,UT	1950	Rock outcrop, Full Gospel Church, Hatfield Bottom
14	UV,UR,UT	2919	Swimming pool deck, Tug Valley Country Club
15	UV,UR,UT	2960	Soil, Tug Valley Country Club
16A	UV,UR,UT	2620	Weathered rock outcrop, outside lined tunnel
17	UV,UR,UT	2642	Rock unlined tunnel, Norfolk & Western Railroad
18	AV,AR,AT	6633	Long Pole Branch

Table 3

Shot 3 Gage Location Data

Station No.	Measurement	Slant Distance Charge cg to Gage ft	Remarks
3-1	UV,UH	38.8	Rock outcrop
3-2	UV,UH	48.1	Rock outcrop
1-1	UV,UH	64.5	Rock outcrop
1-3	UV,UH	76.8	Rock outcrop
5	UV,UH	108	Rock outcrop
6	UV,UR,UT	556	Rock outcrop
7	UV,UR,UT	986	Soil, Hatfield Bottom
8	UV,UR,UT	1519	Soil, lower terrace, Hatfield Bottom
9	UV,UR,UT	1615	Soil, upper terrace, Hatfield Bottom
10	UV,UR,UT	1956	Concrete slab, Full Gospel Church, Hatfield Bottom
11	UV,UR,UT	1957	Rock outcrop, Full Gospel Church, Hatfield Bottom
16	UV,UR,UT	2635	Concrete lined tunnel, Norfolk & Western Railroad
17	UV,UR,UT	2708	Rock unlined tunnel, Norfolk & Western Railroad
18	AV,AR,AT	6633	Long Pole Branch

Table 4

Shot 4 Gage Location Data

Station No.	Measurement	Slant Distance Charge cg to Gage ft	Remarks
4-1	UV,UH	50.1	Rock outcrop
4-2	UV,UH	49.3	Rock outcrop
4-3	UV,UH	55.4	Rock outcrop
1-1	UV,UH	84.3	Rock outcrop
5	UV,UH	131	Rock outcrop
6	UV,UH	576	Rock outcrop
7	UV,UR,UT	1010	Soil, Hatfield Bottom
10	UV,UR,UT	1986	Concrete slab, Full Gospel Church, Hatfield Bottom
11	UV,UR,UT	1988	Rock outcrop, Full Gospel Church, Hatfield Bottom
12	UV,UR,UT	2230	Concrete slab, ground floor, Smith Towers
13	UV,UR,UT	2230	Concrete slab, 6th floor, Smith Towers
16	UV,UR,UT	2668	Concrete lined tunnel, Norfolk & Western Railroad
17	UV,UR,UT	2667	Rock unlined tunnel, Norfolk & Western Railroad
18	AV,AR,AT	6633	Long Pole Branch

Table 5

Shot 5 Gage Location Data

Station No.	Measurement	Slant Distance Charge cg to Gage ft	Remarks
5-1	UV,UH	59.1	Rock outcrop
5-2	UV,UH	58.1	Rock outcrop
4-2	UV,UH	78.3	Rock outcrop
2-2	UV,UH	105	Rock outcrop
5	UV,UH	177	Rock outcrop
6	UV,UR,UT	624	Rock outcrop
7	UV,UR,UT	1059	Soil, Hatfield Bottom
8	UV,UR,UT	1594	Soil, lower terrace, Hatfield Bottom
9	UV,UR,UT	1690	Soil, upper terrace, Hatfield Bottom
14	UV,UR,UT	2932	Swimming pool, Tug Valley Country Club
15	UV,UR,UT	2971	Soil, Tug Valley Country Club
16	UV,UR,UT	2698	Concrete lined tunnel, Norfolk & Western Railroad
17	UV,UR,UT	2771	Rock unlined tunnel, Norfolk & Western Railroad
18	AV,AR,AT	6633	Long Pole Branch

Table 6

Close-in Gage Canisters: Inclination and Orientation

Shot No.	Canister Location	Canister Strike	Canister Dip	Bearing to Shot Hole
1	1-1	N26°E	15°SE	S30°E
1	1-2	N75°E	13.5°SE	S45°E
1	1-3	N30°E	9.5°SW	S60°E
1	1-4	N10°W	10°NE	S75°E
1	5	N 6°E	4°SE	S83°E
2	1-1	N28°E	13.5°SE	N82°E
2	2-2	N79°E	2.5°NW	S79°E
2	1-3	N35°W	10°NE	N65°E
2	1-4	N12°W	9°NE	N65°E
2	5	N 2°W	3°NE	N60°E
3	3-1	N 8°E	12°SE	N 7°E
3	3-2	N10°E	1°SE	S60°E
3	1-1	N38°E	16°NW	S83°E
3	1-3	N36°W	9°SW	E
3	5	N19°E	4°NW	N80°E
4	4-1	N79°E	9°NW	S11°E
4	4-2	N86°W	12°SW	S76°E
4	4-3	N69°E	12°NW	N84°E
4	1-1	N28°E	13°NW	N70°E
4	5	N25°E	3°NW	N69°E
5	5-1	N16°E	8°NW	S25°E
5	5-2	N60°W	13°SW	S84°E
5	4-2	N88°W	13°SW	N75°E
5	2-2	-	0°	N70°E
5	5	N19°W	5°SW	N69°E

Table 7

Explosives

Shot No.	Primary Explosive: Number of Cartridges	Primary Explosive: Total Weight lb	Booster: Number of Cartridges	Booster: Total Weight lb	Length of: Explosive Column ft	Length of: Stemming ft	Length of: Charge Hole ft
1	3	30	1	1.2	7.8	21.1	28.9
2	10	100	3	3.7	24.0	21.1	45.0
3	10	100	3	3.7	24.0	23.0	47.0
4	30	300	9	11.0	71.0	13.0	84.0
5	30	300	23	28.0	75.0	18.0	93.0

Table 8 Shot No. 1: Peak Particle Motion and Duration From a 31 lb Stemmed Detonation

Station No.	Gage Orientation	Site Media	Slant Distance ft	Duration msec	Horizontal/Vertical Correction Multiplier	Corrected Peak Particle Velocity in./sec	Peak Particle Acceleration g's
1-1	UV	Rock	40.3	60	1.0353	1.10	
	UH			80	0.9765	0.77	
1-2	UV	Rock	42.7	72	1.0284	1.38	
	UH			60	0.9998	0.73	
1-3	UV	Rock	44	40	1.0139	1.72	
	UH			40	0.9853	0.54	
1-4	UV	Rock	54.6	44	1.0154	0.92	
	UH			52	0.9883	0.42	
5	UV	Rock	66.6	44	1.0024	1.34	
	UH			50	0.9989	0.57	
6	UV	Rock	515	140	--	0.0348	
	UR			110	--	0.0495	
	UT			130	--	0.0309	
7	UV	Soil	943	160	--	0.0164	
	UR			620	--	0.0175	
	UT			580	--	0.0067	
8	UV	Soil	1482	1280	--	0.0222	
	UR			1240	--	0.0315	
	UT			1240	--	0.0117	
9	UV	Soil	1579	500	--	0.0176	
	UR			560	--	0.0123	
	UT			1200	--	0.0080	
10	UV	Concrete	1916	290	--	0.0048	
	UR			290	--	0.0024	
	UT			360	--	0.0035	
11	UV	Rock	1918	340	--	0.0033	
	UR			340	--	0.0026	
	UT			300	--	0.0012	
16	UV	Concrete	2610	100	--	0.0021	
	UR			120	--	0.0015	
	UT			440	--	0.0009	
17	UV	Rock	2683	70	--	0.0019	
	UR			90	--	0.0014	
	UT			320	--	0.0006	
18	AV	Soil	6633	--	--		<0.0090
	AR			--	--		<0.0090
	AT			--	--		<0.0090

Table 9. Shot No. 2: Peak Particle Motion and Duration From a 104 lb Stemmed Detonation

Station No.	Gage Orientation	Site Media	Slant Distance ft	Duration msec	Horizontal/ Vertical Correction Multiplier	Corrected Peak Particle Velocity in./sec	Peak Particle Acceleration g's
1-1	UV	Rock	47	86	1.0284	1.58	
	UH			57	0.9819	1.74	
2-2	UV	Rock	31.3	26	1.0011	15.0	
	UH			10	0.9998	3.50	
1-3	UV	Rock	58.4	60	1.0154	0.94	
	UH			56	0.9853	0.50	
1-4	UV	Rock	73.2	38	1.0223	0.83	
	UH			50	0.9883	0.45	
5	UV	Rock	88.7	36	1.0013	0.99	
	UH			32	0.9989	0.71	
6	UV	Rock	537	160	--	0.0483	
	UR			100	--	0.0732	
	UT			90	--	0.0449	
7	UV	Soil	970	220	--	0.0223	
	UR			630	--	0.0252	
	UT			>800	--	0.0110	
10	UV	Concrete	1948	380	--	0.0048	
	UR			470	--	0.0040	
	UT			360	--	0.0045	
11	UV	Rock	1950	260	--	0.0036	
	UR			320	--	0.0041	
	UT			530	--	0.0012	
14	UV	Concrete	2919	1070	--	0.0022	
	UR	(Soil)		1250	--	0.0022	
	UT			>1140	--	0.0011	
15	UV	Soil	2960	840	--	0.0028	
	UR			1100	--	0.0034	
	UT			1060	--	0.0020	
16A	UV	Rock	2620	500	--	0.0019	
	UR			250	--	0.0021	
	UT			450	--	0.0013	
17	UV	Rock	2642	300	--	0.0079	
	UR			360	--	0.0104	
	UT			430	--	0.0065	
18	AV	Soil	6633	--	--		<0.0090
	AR			--			<0.0090
	AT			--			<0.0090

Table 10. Shot No. 3: Peak Particle Motion and Duration From a 104 lb Stemmed Detonation

Station No.	Gage Orientation	Site Media	Slant Distance ft	Duration msec	Horizontal/ Vertical Correction Multiplier	Corrected Peak Particle Velocity in./sec	Peak Particle Acceleration g's
3-1	UV	Rock	38.8	28	1.0223	2.86	
	UH			32	0.9985	0.73	
3-2	UV	Rock	48.1	28	1.0002	0.91	
	UH			22	0.9999	0.26	
1-1	UV	Rock	64.5	44	1.0403	0.49	
	UH			56	0.9715	0.15	
1-3	UV	Rock	76.8	33	1.0125	0.24	
	UH			22	0.9919	0.11	
5	UV	Rock	108	42	1.0024	0.51	
	UH			36	0.9981	0.17	
6	UV	Rock	556	150	--	0.055	
	UR			80	--	0.052	
	UT			70	--	0.049	
7	UV	Soil	986	280	--	0.009	
	UR			620	--	0.005	
	UT			710	--	0.008	
8	UV	Soil	1519	1100	--	0.0092	
	UR			430	--	0.0151	
	UT			1320	--	0.0058	
9	UV	Soil	1615	800	--	0.0062	
	UR			840	--	0.0061	
	UT			850	--	0.0041	
10	UV	Concrete	1956	330	--	0.0018	
	UR			300	--	0.0018	
	UT			360	--	0.0020	
11	UV	Rock	1957	370	--	0.0024	
	UR			380	--	0.0018	
	UT			280	--	0.0010	
16	UV	Concrete	2635	530	--	0.0009	
	UR			300	--	0.0011	
	UT			490	--	0.0007	
17	UV	Rock	2708	300	--	0.0012	
	UR			190	--	0.0009	
	UT			320	--	0.0004	
18	AV	Soil	6633	--	--		<0.0048
	AR			--	--		<0.0048
	AT			--	--		<0.0048

Table 11. Shot No. 4: Peak Particle Motion and Duration From a 311 lb Stemmed Detonation

Station No.	Gage Orientation	Site Media	Slant Distance ft	Duration msec	Horizontal/ Vertical Correction Multiplier	Corrected Peak Particle Velocity in./sec	Peak Particle Acceleration g's
4-1	UV	Rock	50.1	--	1.0125	19.1	
	UH			10	0.9878	13.0	
4-2	UV	Rock	49.3	55	1.0223	10.9	
	UH			62	0.9993	1.97	
4-3	UV	Rock	55.4	58	1.0403	4.75	
	UH			23	0.9974	1.61	
1-1	UV	Rock	84.3	76	1.0263	0.85	
	UH			62	0.9885	0.72	
5	UV	Rock	131	20	1.0014	0.75	
	UH			28	0.9993	0.94	
6	UV	Rock	576	180	--	0.0562	
	UR			50	--	0.0997	
	UT			80	--	0.0646	
7	UV	Soil	1010	310	--	0.0339	
	UR			730	--	0.0352	
	UT			740	--	0.0154	
10	UV	Concrete	1986	540	--	0.0090	
	UR			480	--	0.0054	
	UT			550	--	0.0055	
11	UV	Rock	1988	490	--	0.0058	
	UR			160	--	0.0048	
	UT			600	--	0.0024	
12	UV	Concrete	2230	820	--	0.0060	
	UR			650	--	0.0043	
	UT			840	--	0.0032	
13	UV	Concrete*	2230	850	--	0.007	
	UR			520	--	0.0049	
	UT			>760	--	0.004	
16	UV	Concrete	2668	520	--	0.0052	
	UR			170	--	0.0047	
	UT			410	--	0.0035	
17	UV	Rock	2667	600	--	0.0050	
	UR			540	--	0.0028	
	UT			530	--	0.0016	
18	AV	Soil	6633	--	--		<0.0048
	AR			--	--		<0.0048
	AT			--	--		<0.0048

* 6th floor Smith Towers.

Table 12. Shot No. 5: Peak Particle Motion and Duration From a 328 lb Stemmed Detonation

Station No.	Gage Orientation	Site Media	Slant Distance ft	Duration msec	Horizontal/ Vertical Correction Multiplier	Corrected Peak Particle Velocity in./sec	Peak Particle Acceleration g's
5-1	UV	Rock	59.1	38	1.0098	6.16	
	UH			20	0.9958	1.69	
5-2	UV	Rock	58.1	40	1.0263	3.72	
	UH			40	0.9911	0.92	
4-2	UV	Rock	78.3	44	1.0263	0.46	
	UH			42	0.9978	0.24	
2-2	UV	Rock	105	36	1.0000	0.85	
	UH			26	1.0000	0.43	
5	UV	Rock	177	42	1.0038	0.32	
	UH			30	0.9978	0.39	
6	UV	Rock	624	130	--	0.0436	
	UR			60	--	0.0455	
	UT			50	--	0.0231	
7	UV	Soil	1059	280	--	0.0139	
	UR			630	--	0.0145	
	UT			740	--	0.0087	
8	UV	Soil	1594	960	--	0.0103	
	UR			400	--	0.0132	
	UT			1320	--	0.0081	
9	UV	Soil	1690	680	--	0.0084	
	UR			660	--	0.0065	
	UT			620	--	0.0050	
14	UV	Concrete	2932	1120	--	0.0010	
	UR	(Soil)		440	--	0.0010	
	UT			300	--	0.0003	
15	UV	Soil	2971	320	--	0.0015	
	UR			470	--	0.0015	
	UT			420	--	0.0012	
16	UV	Concrete	2698	560	--	0.0016	
	UR			90	--	0.0014	
	UT			390	--	0.0010	
17	UV	Rock	2771	500	--	0.0013	
	UR			360	--	0.0013	
	UT			470	--	0.0007	
18	AV	Soil	6633		--		<0.0048
	AR				--		<0.0048
	AT				--		<0.0048

Table 13

Analysis of Variance for the Regression Plotted on Figure 13 $V = 22.61\ (R/W^{1/2})^{-1.687}$

Source	DF	SS	MS	F
Total	49	87.53		
Reg	1	83.87	83.87	793.05
Resid	48	4.76	0.11	

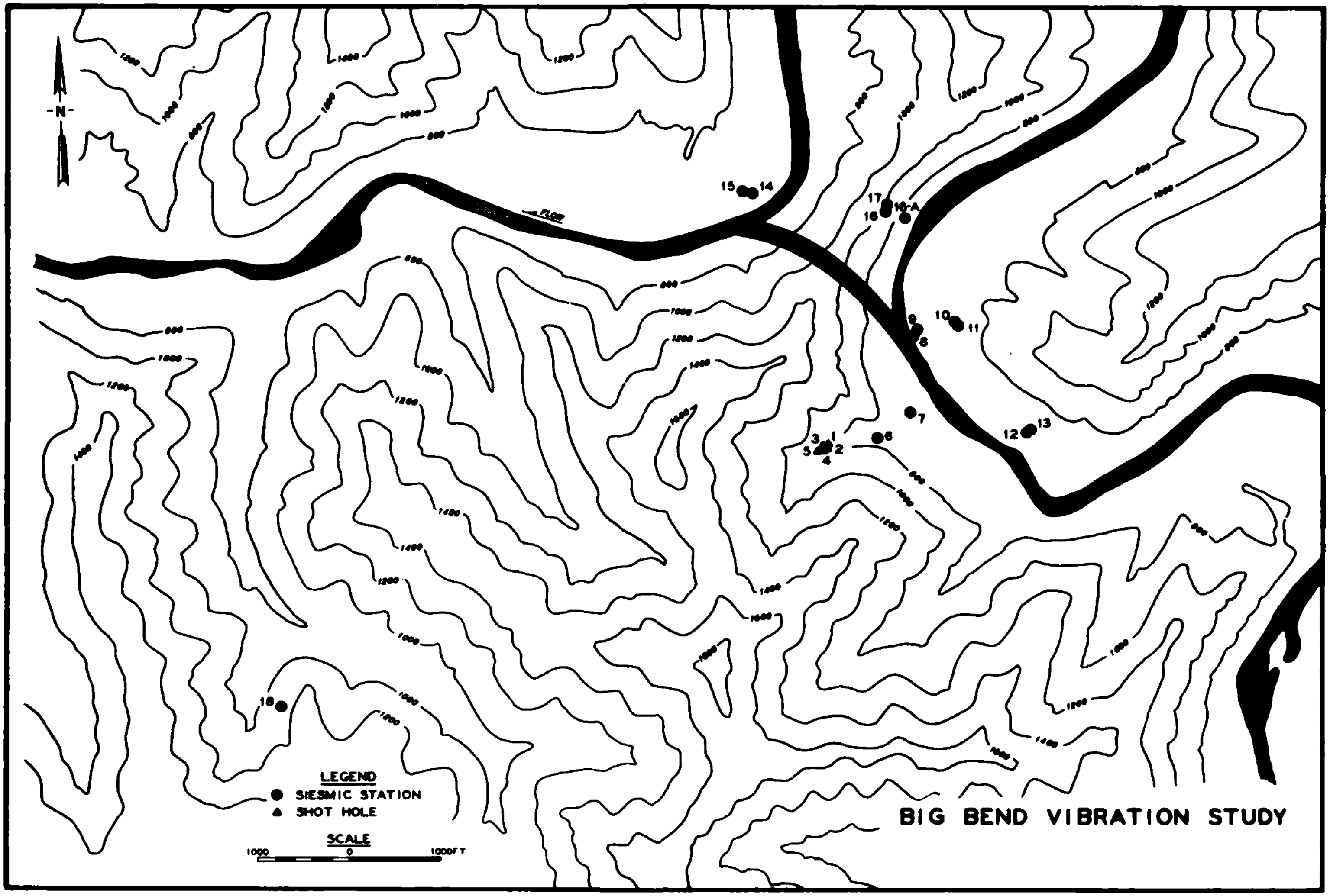

Figure 1. Shot hole and seismic blast monitoring station locations.

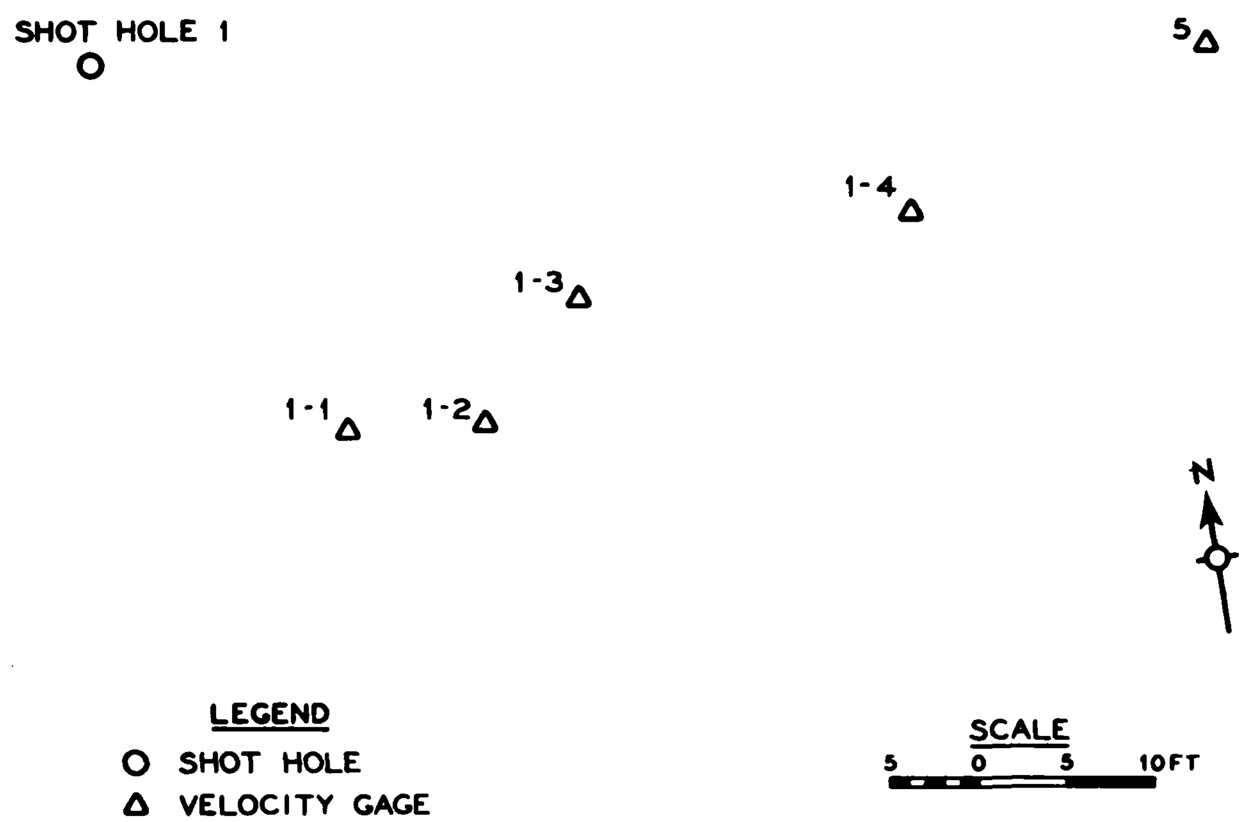

Figure 2. Shot 1, close-in gage locations.

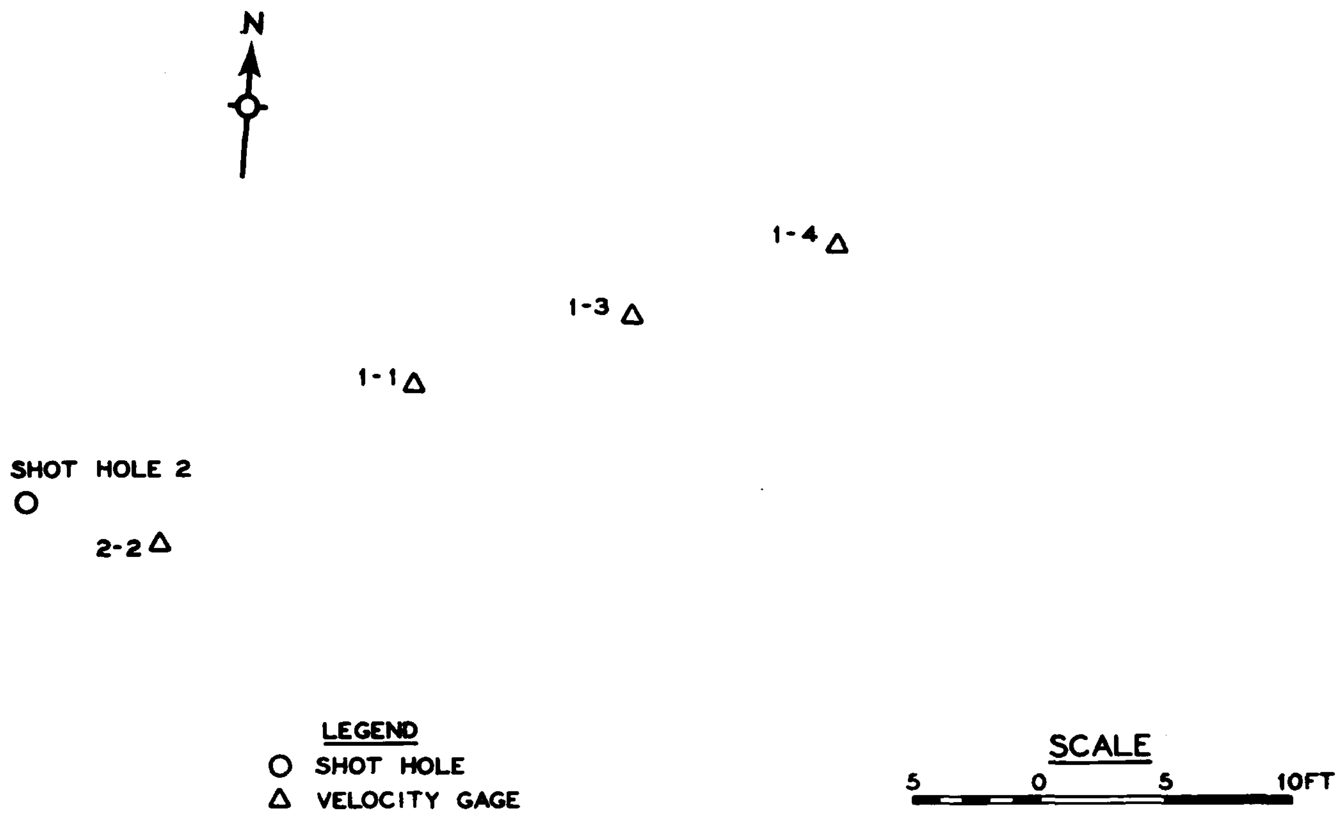

Figure 3. Shot 2, close-in gage locations.

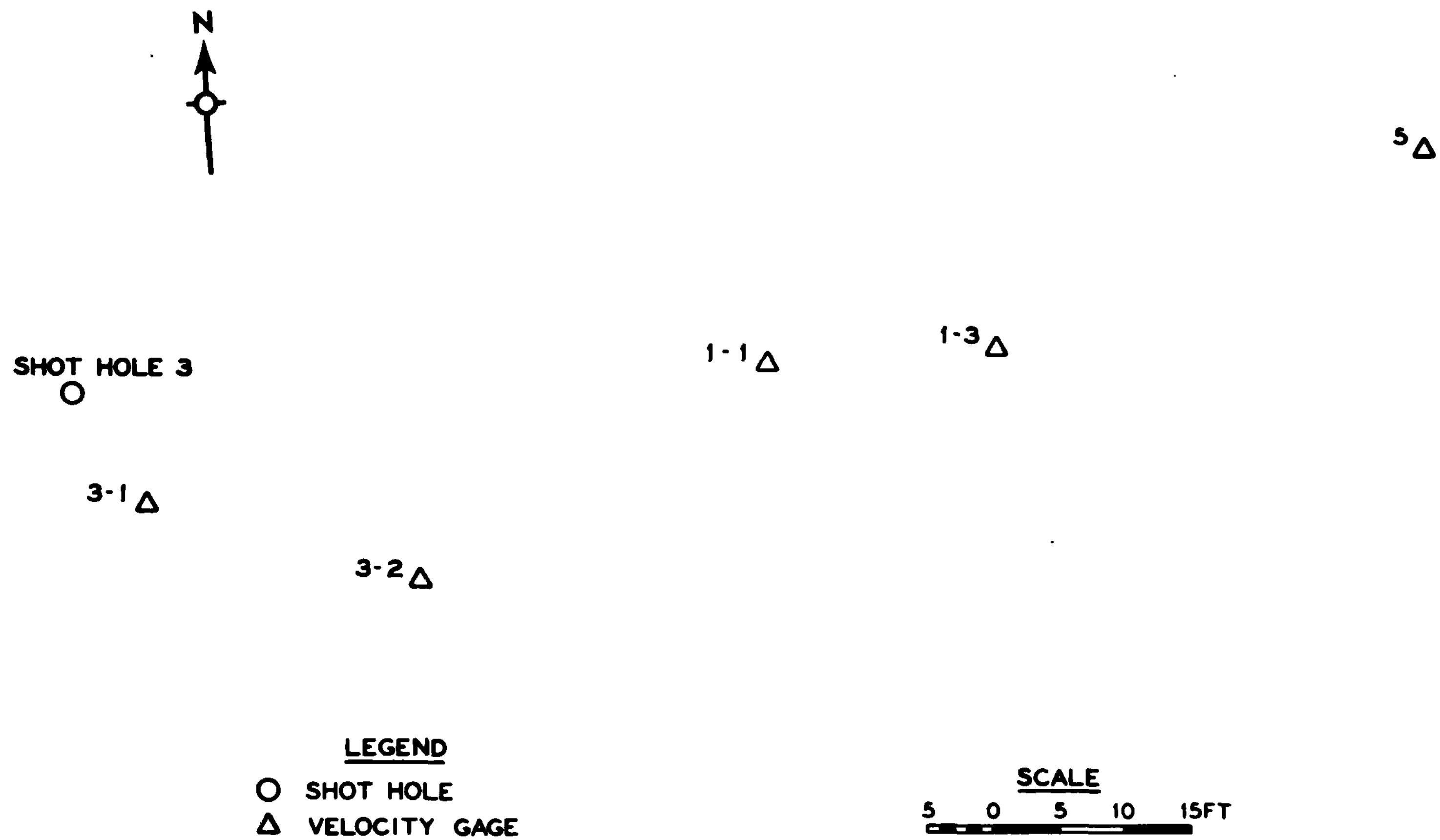

Figure 4. Shot 3, close-in gage locations.

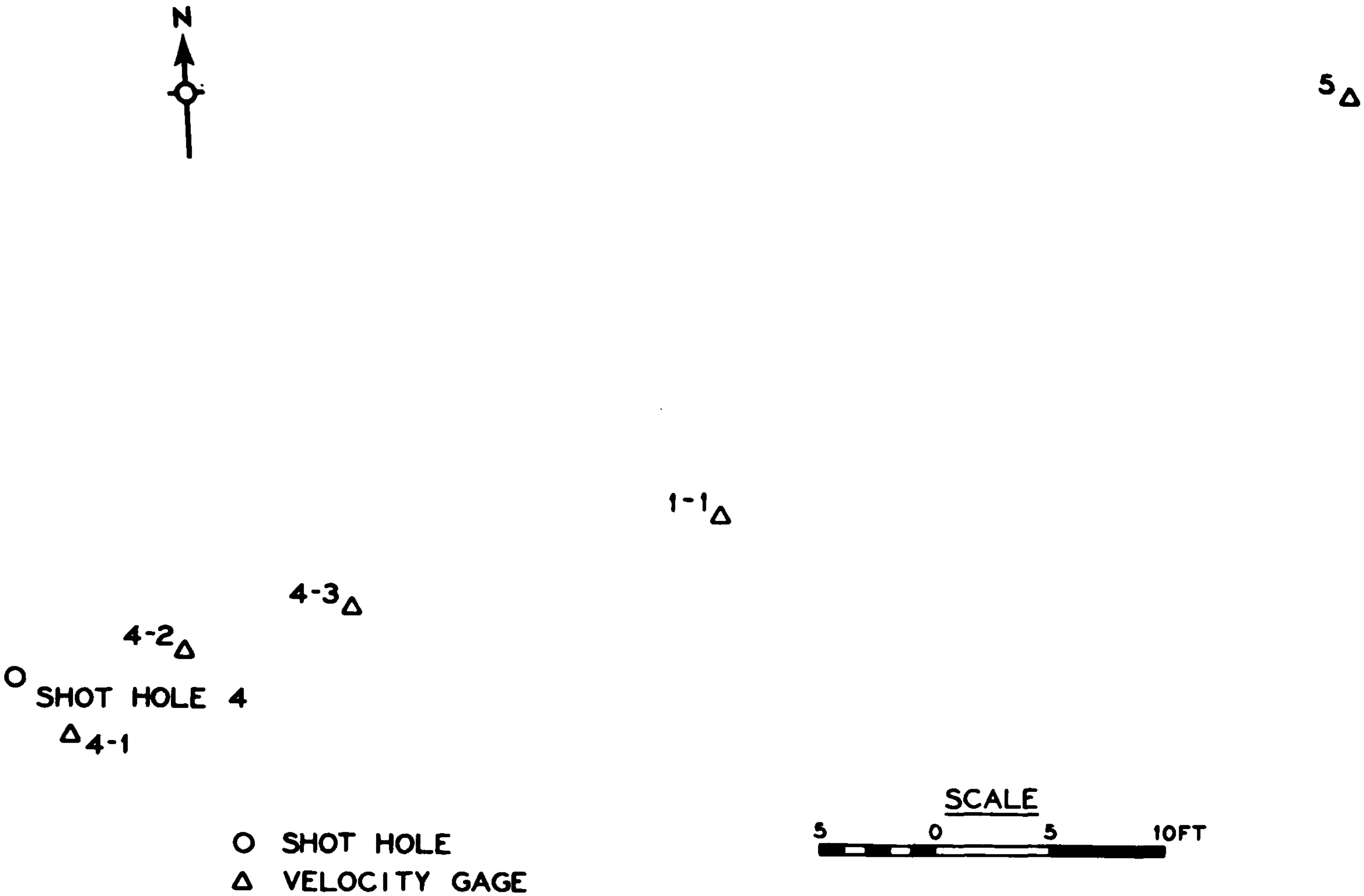

Figure 5. Shot 4, close-in gage locations.

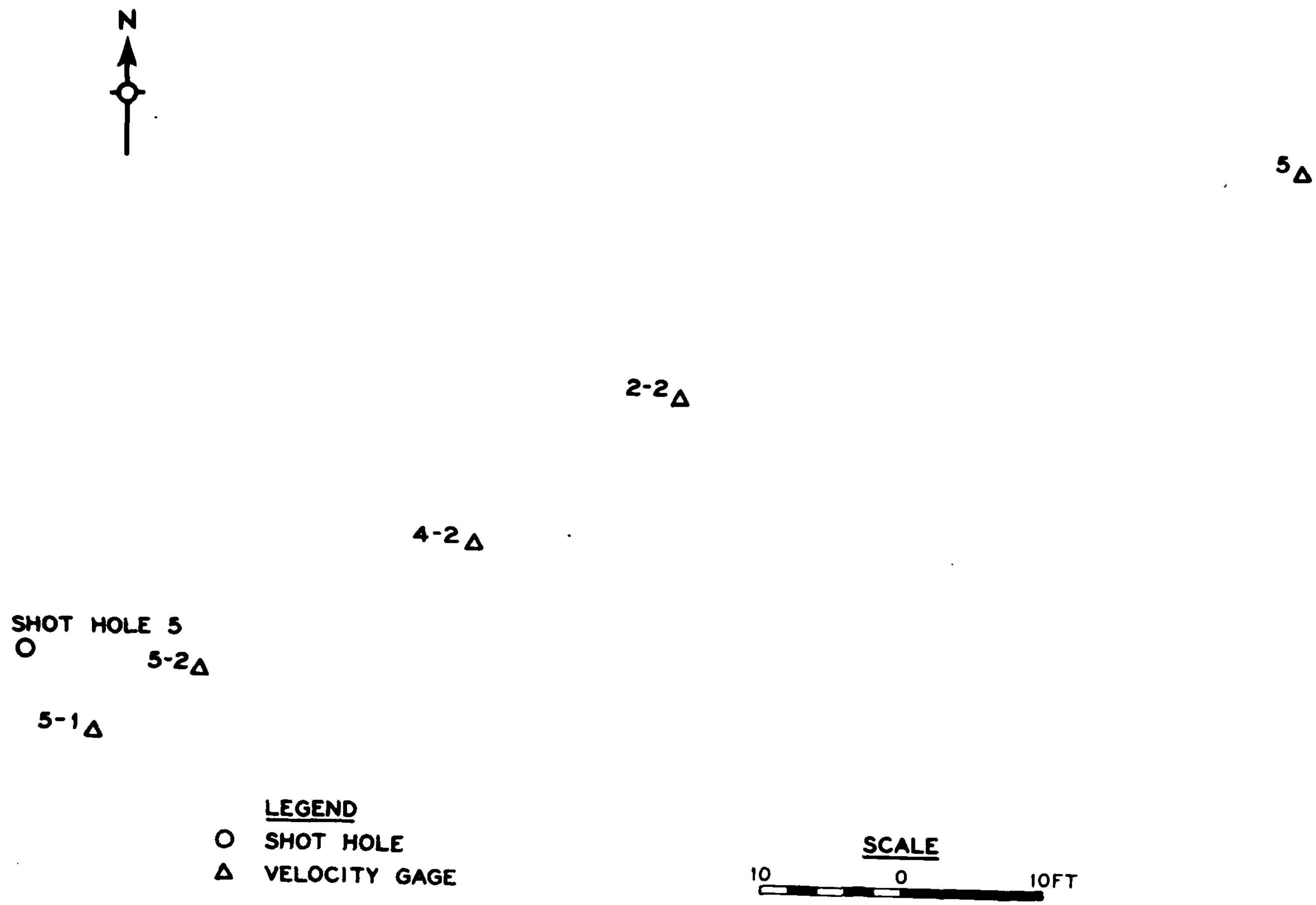

Figure 6. Shot 5, close-in gage locations.

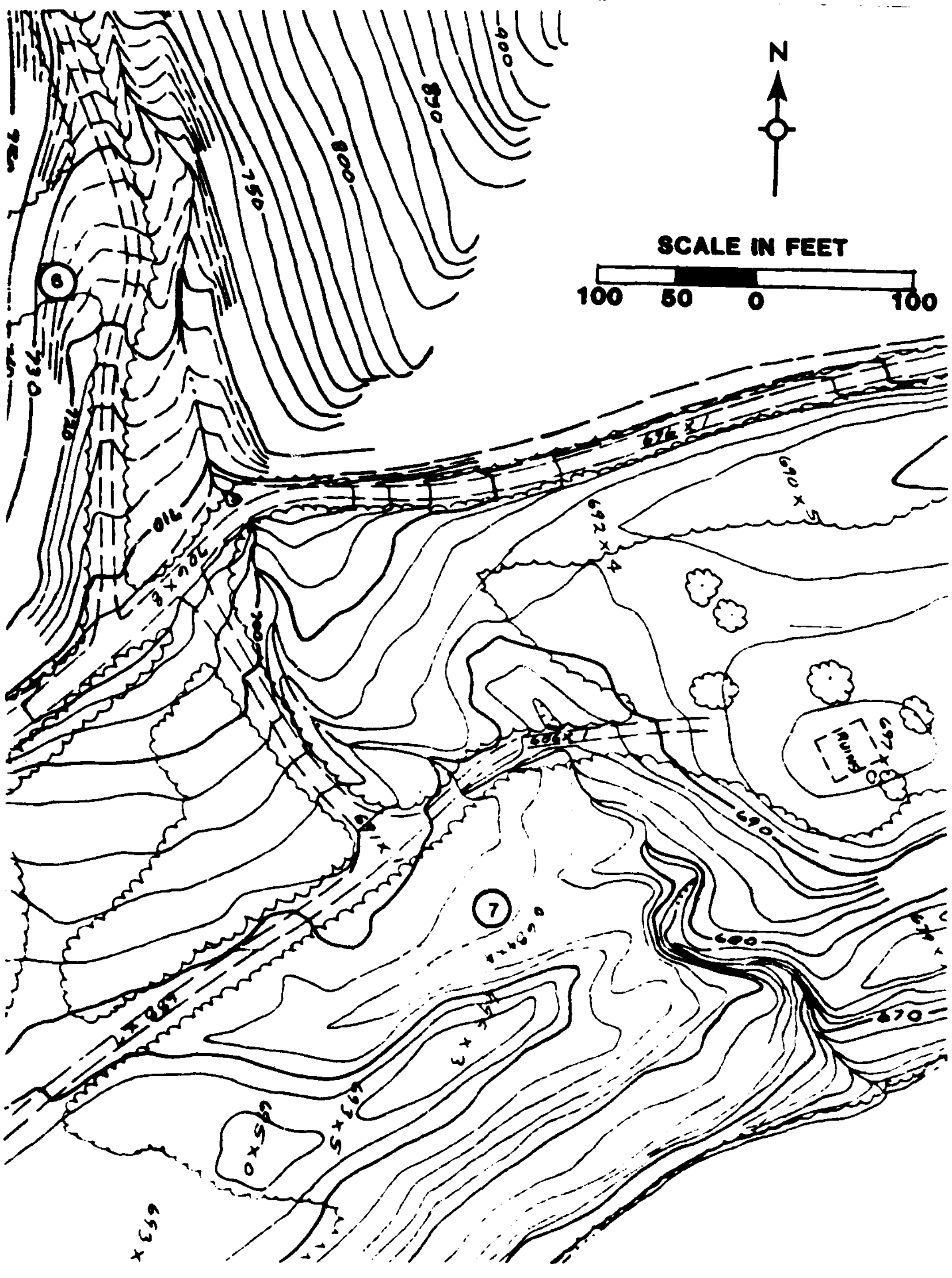

Figure 7. Seismic blast Monitoring Stations 6 and 7, Hatfield Bottom.

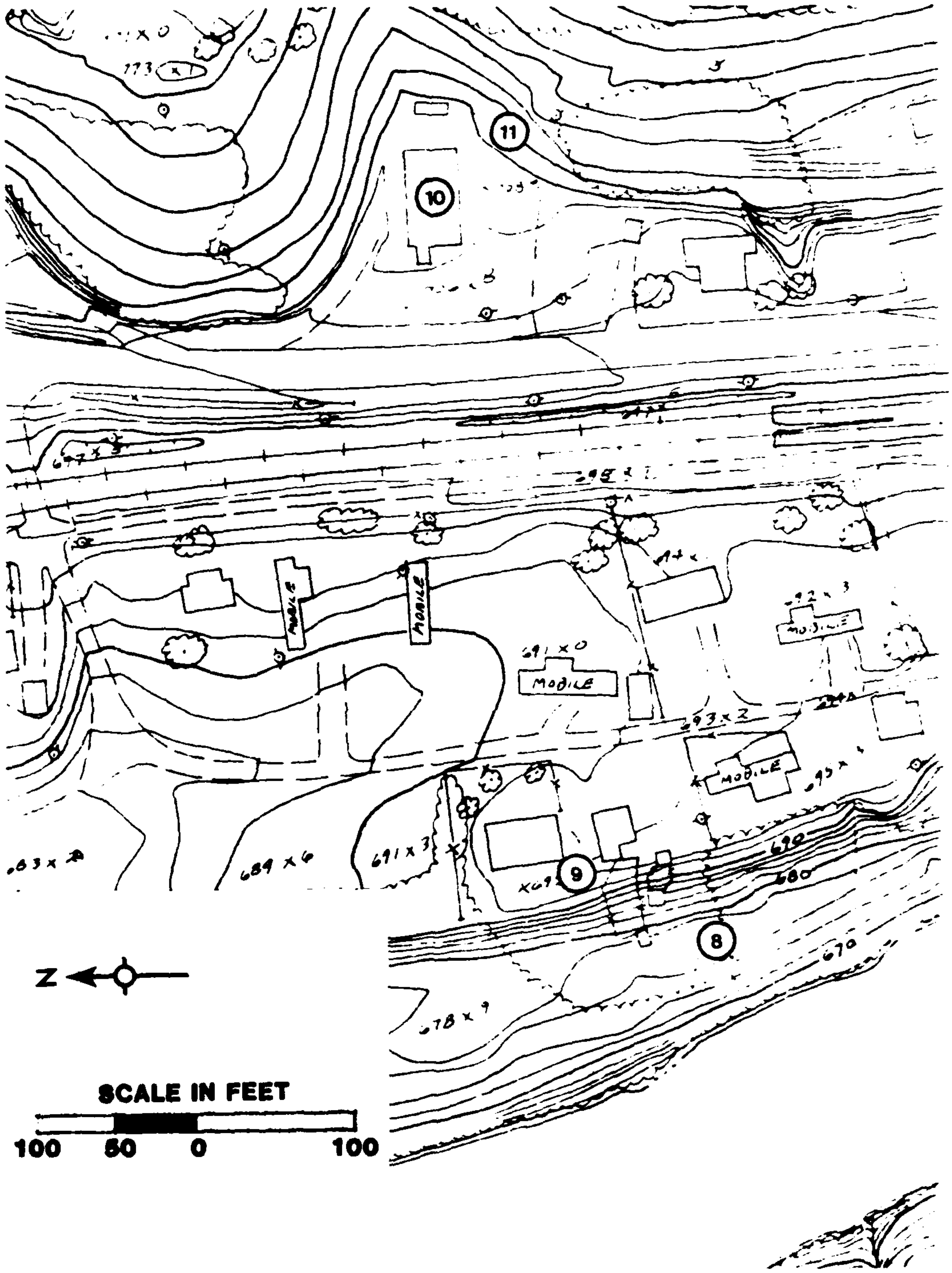

Figure 8. Seismic blast Monitoring Stations, 8, 9, 10 and 11, Hatfield Bottom.

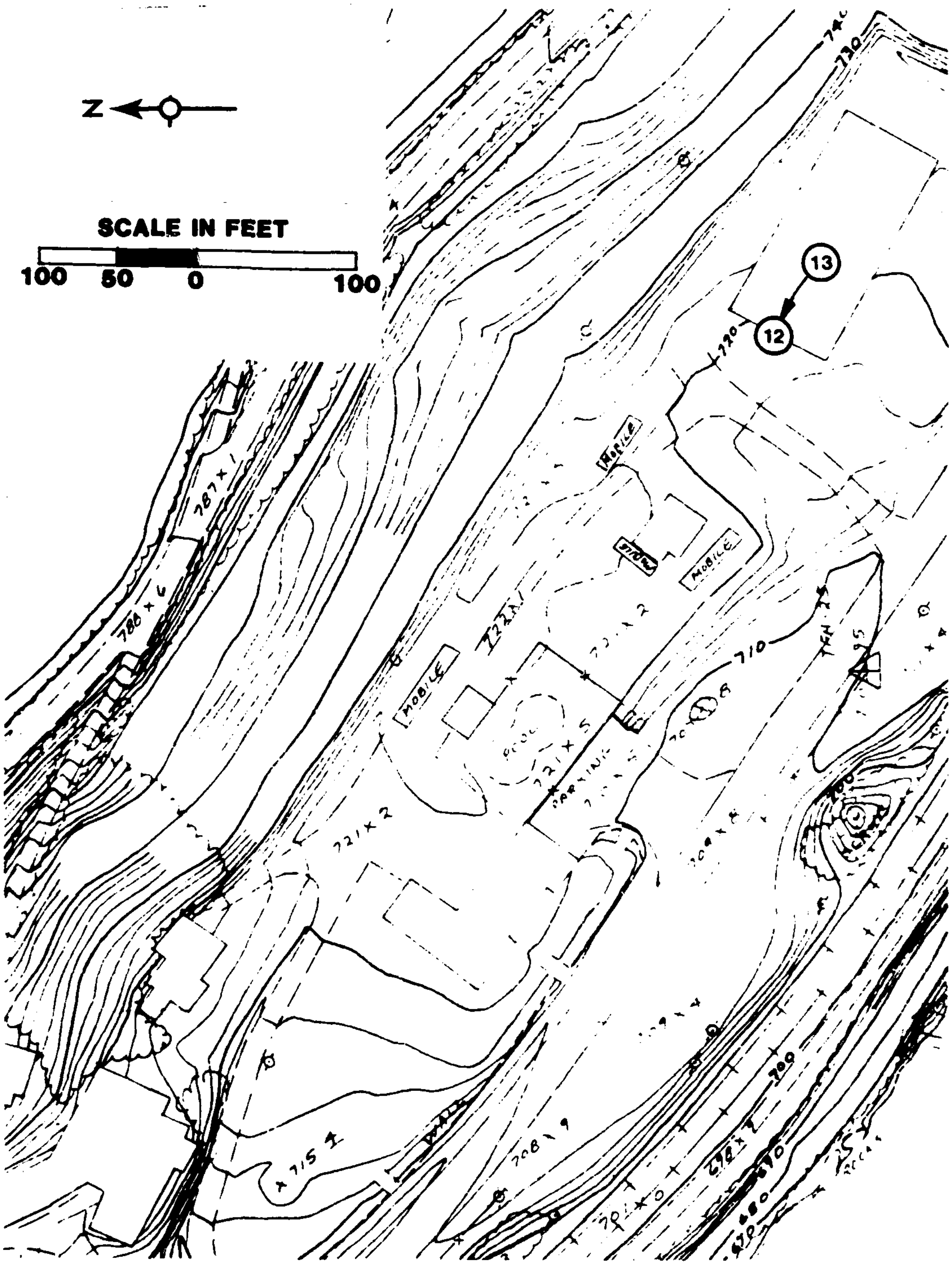

Figure 9. Seismic blast Monitoring Stations 12 and 13, Smith Towers, (ground floor and 6th floor, respectively).

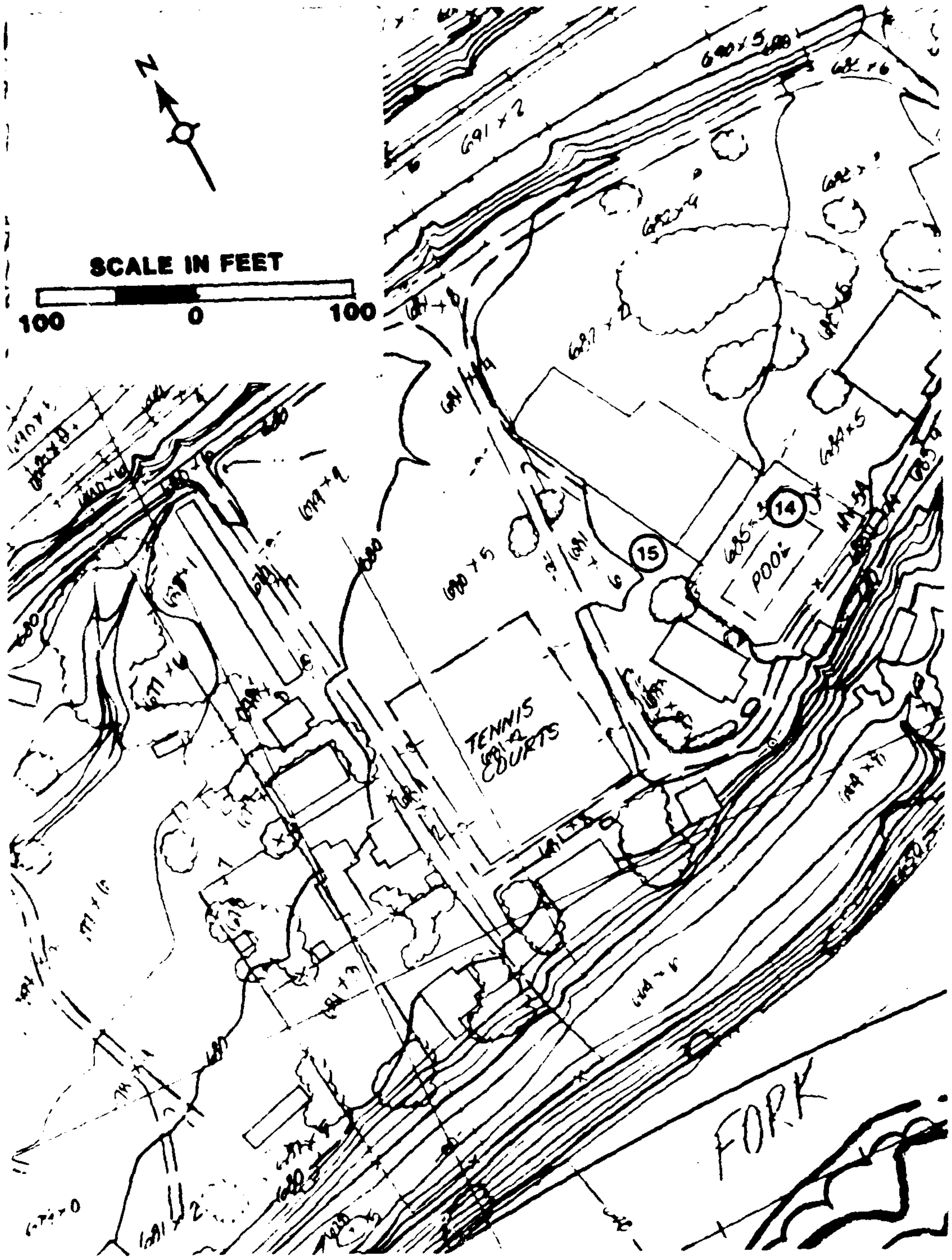

Figure 10. Seismic blast Monitoring Stations 14 and 15, Tug Valley Country Club.

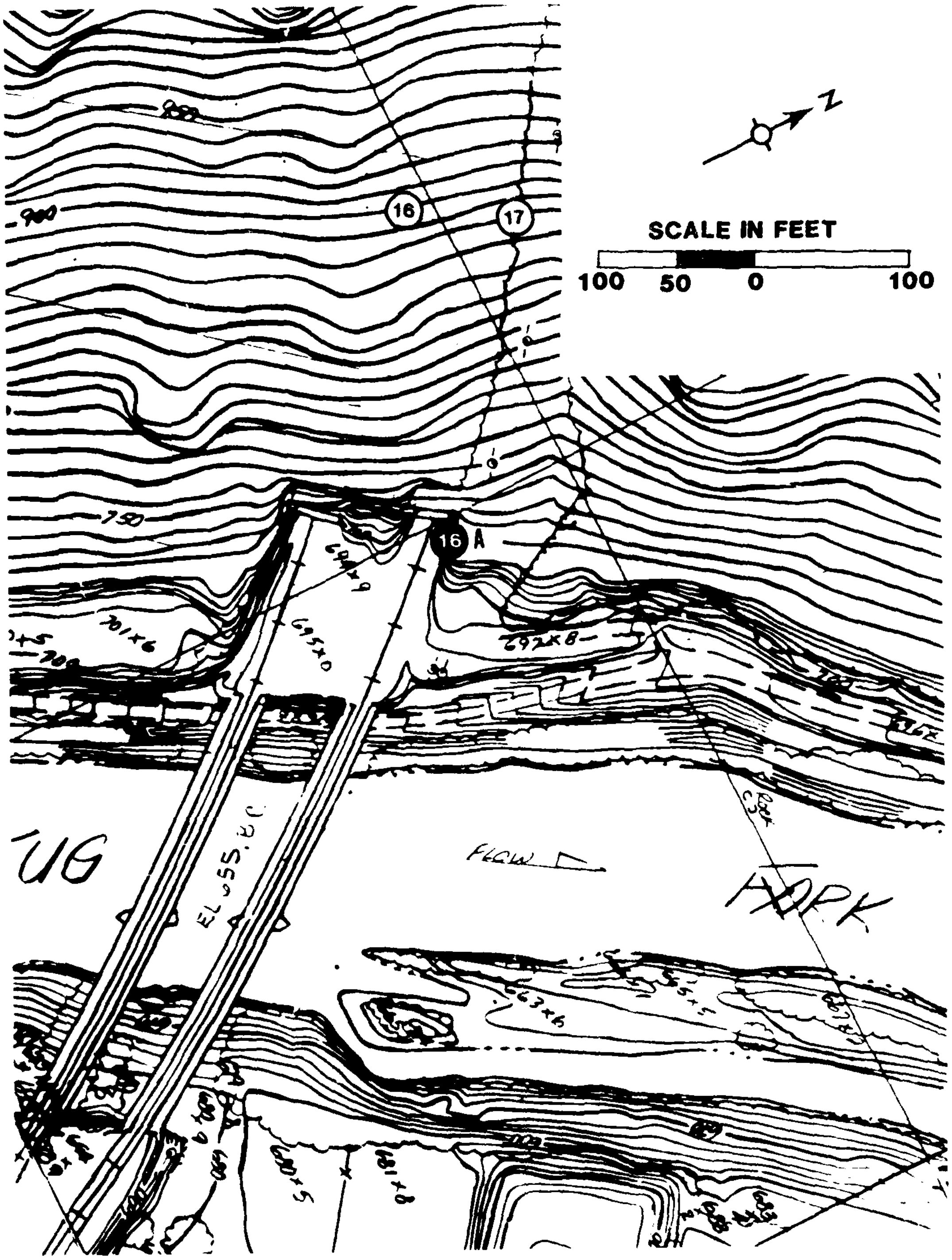

Figure 11. Seismic blast Monitoring Stations 16, 16A and 17, Norfolk & Western Railroad tunnels.

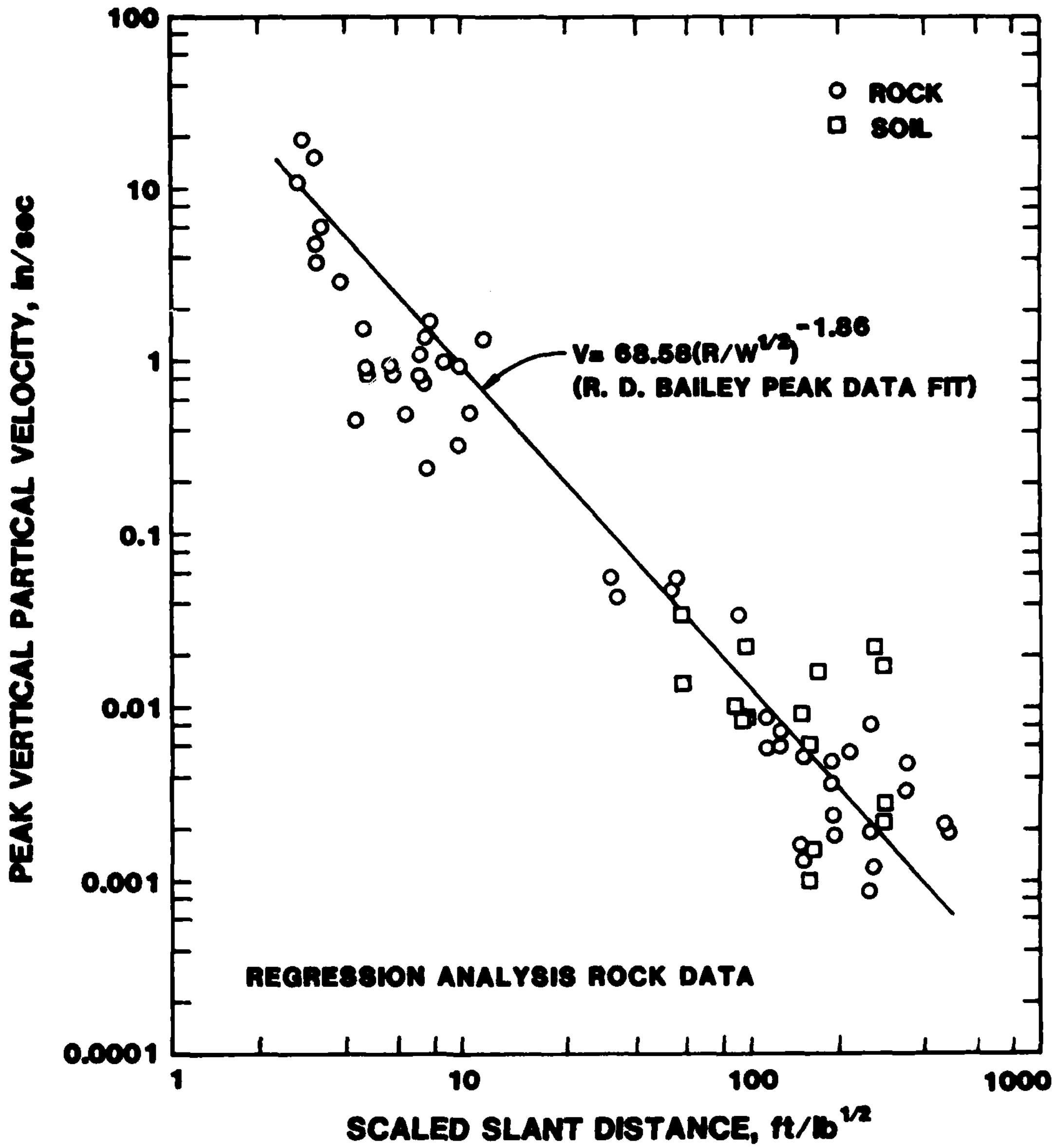

Figure 12. Comparison of peak vertical particle velocity to R. D. Bailey data (Reference 1) regression line.

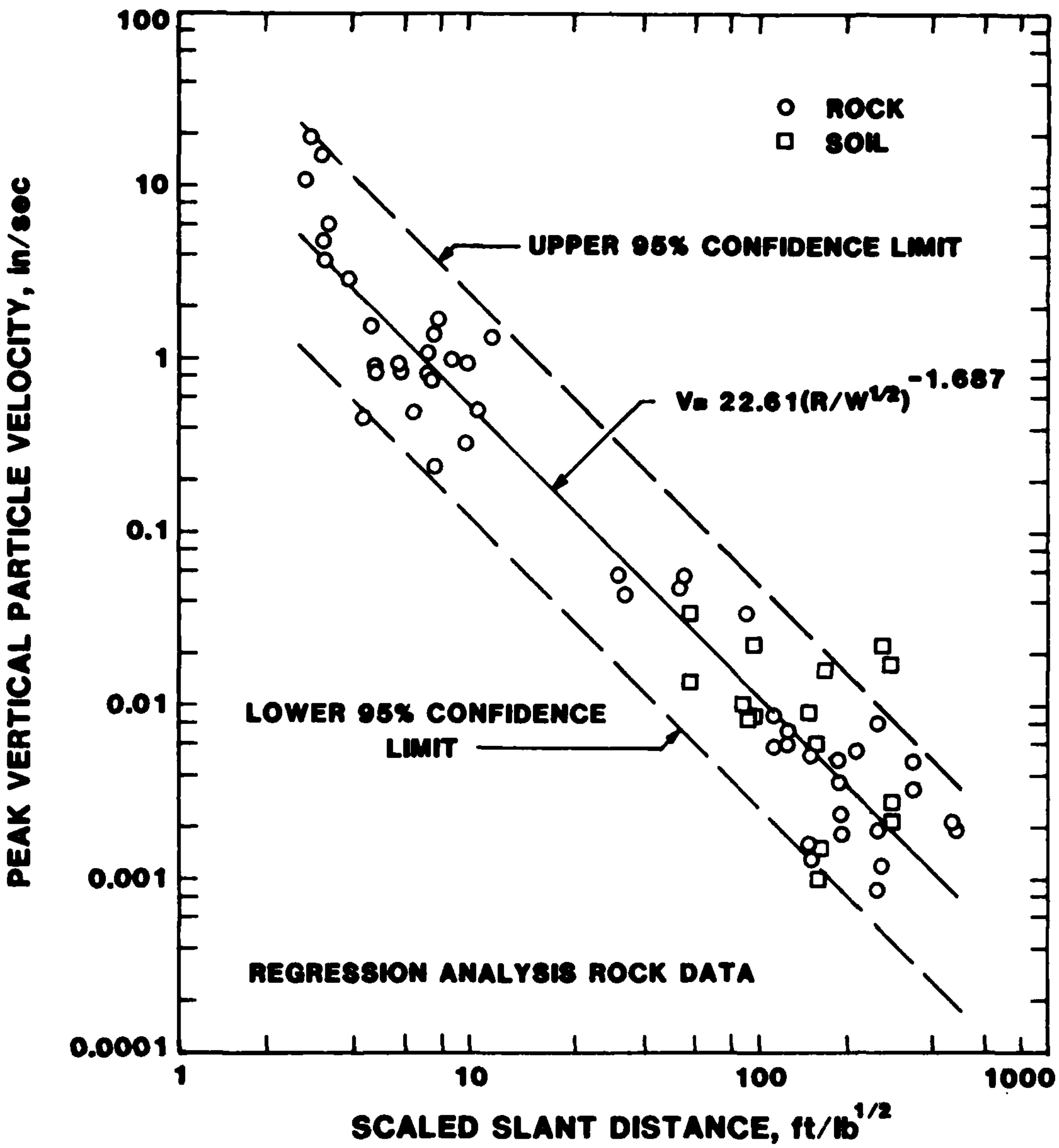

Figure 13. Peak vertical particle velocity with regression curve (rock data only) and 95% confidence limit.

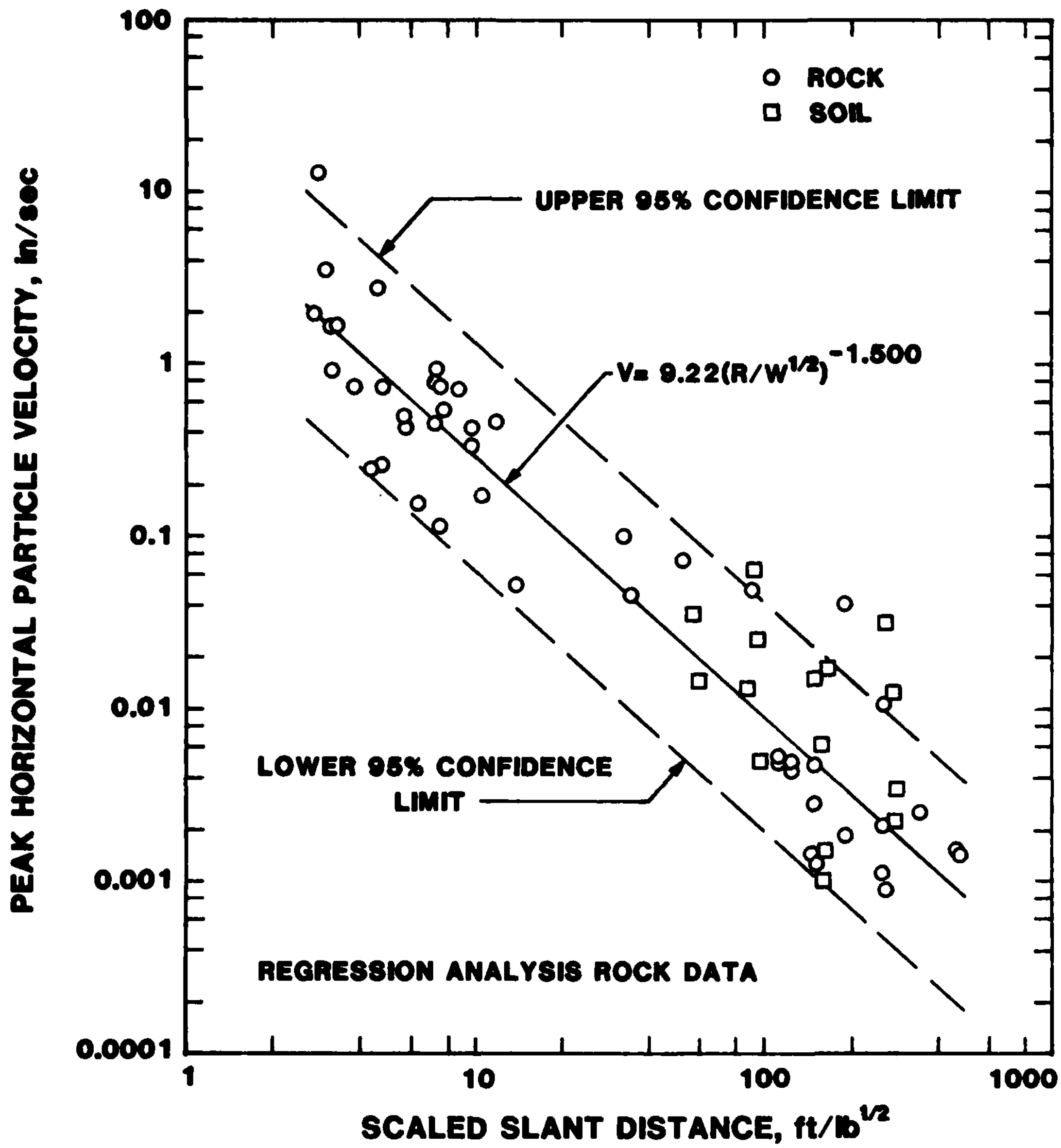

Figure 14. Peak horizontal particle velocity data with regression curve and 95% confidence band.

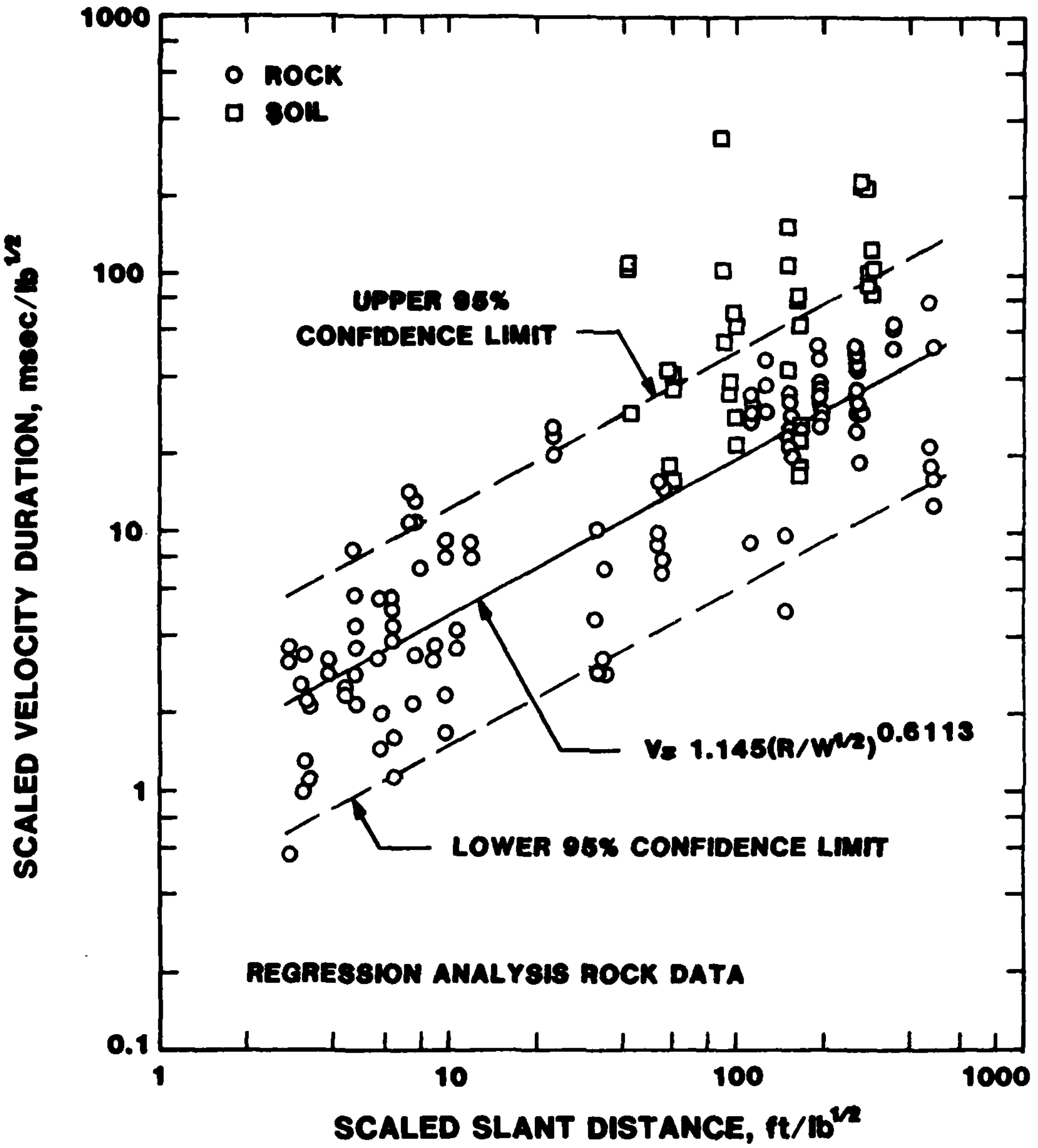

Figure 15. Scaled velocity duration versus distance.

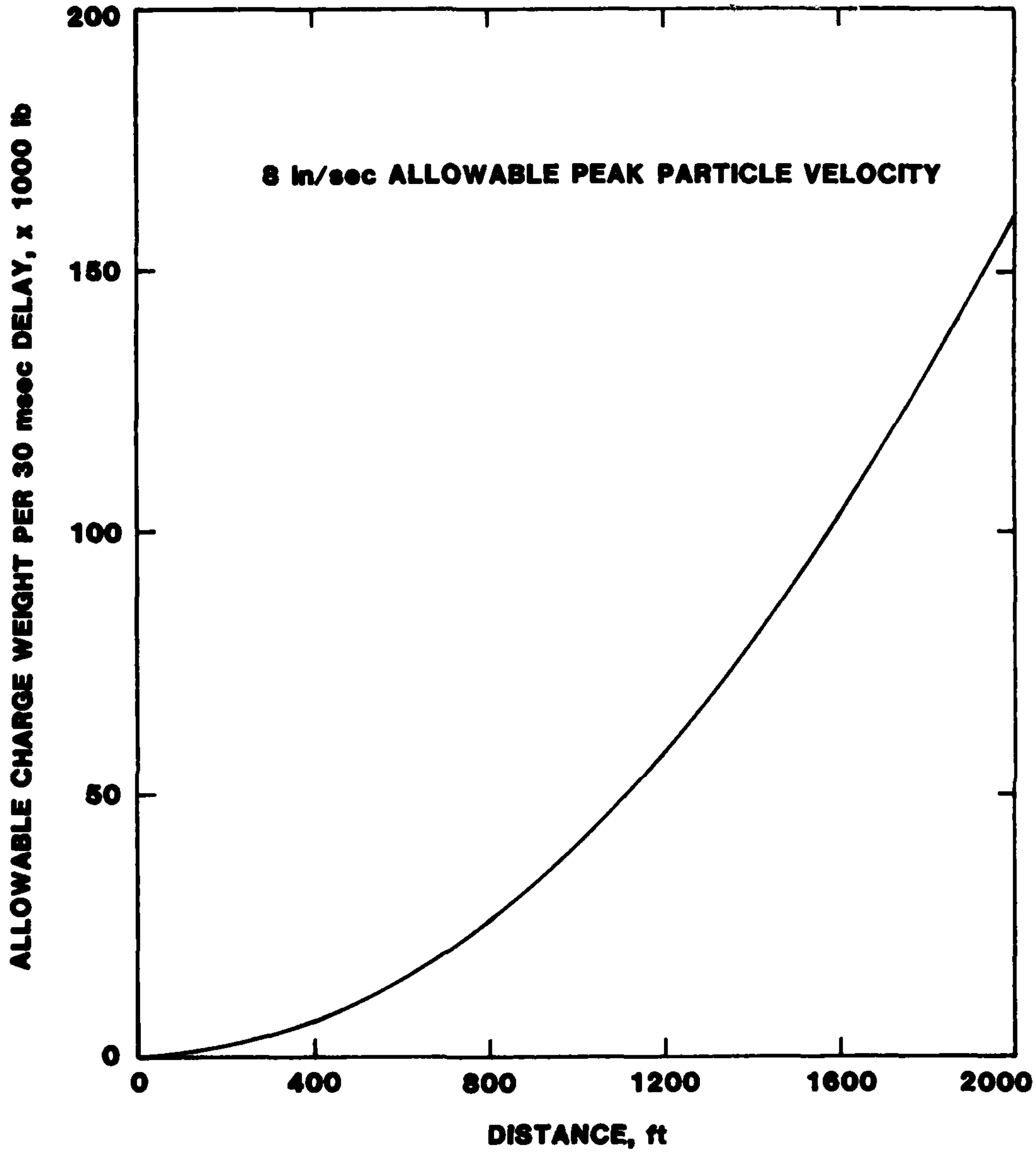

Figure 16. Allowable charge weight per 30 msec delay versus distance for 8 in/sec peak particle velocity at the unlined Norfolk & Western Railroad tunnel.

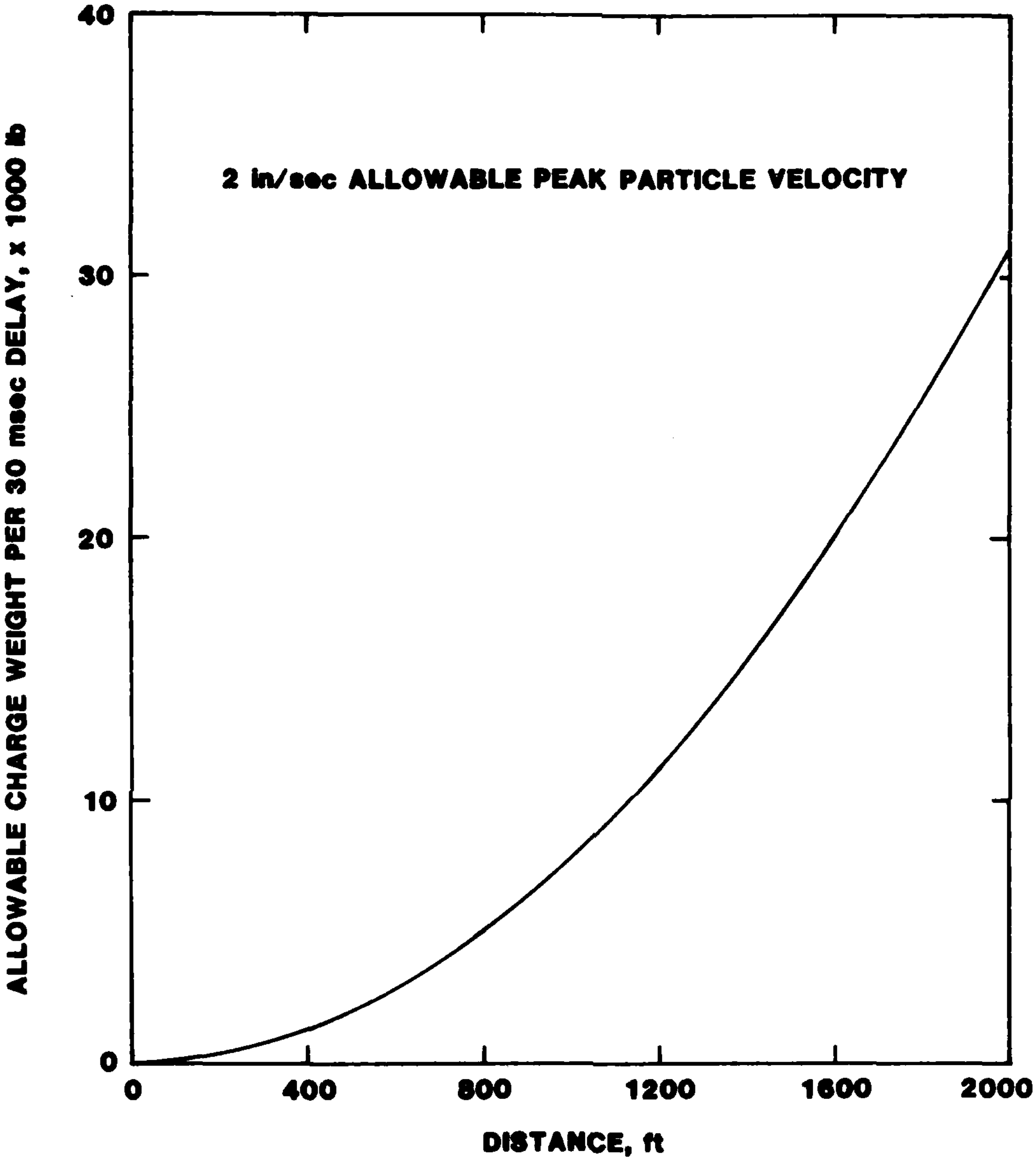

Figure 17. Allowable charge weight per 30 msec delay versus distance for 2 in/sec peak particle velocity at nearby structure.

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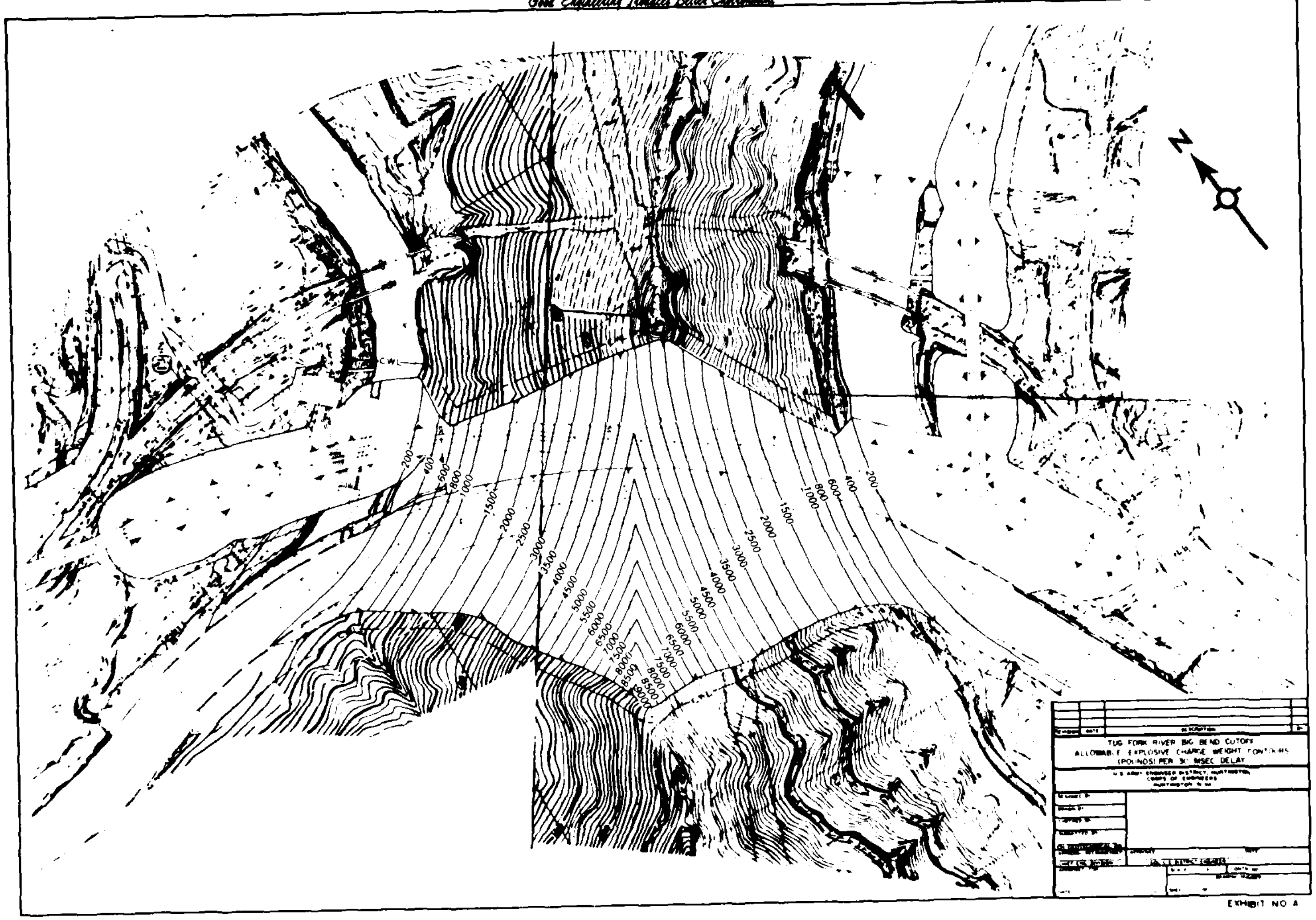

Figure 18. Blasting contour map.

References

1. W. R. Bechtell, "Project R. D. Bailey Experimental Excavation Program," TR E-75-2, June 1975, U.S. Army Engineer Waterways Experiment Station, Explosive Excavation Research Laboratory, Livermore, California.

2. C. E. Joachim, "ESSEX-DIAMOND ORE RESEARCH PROGRAM, Tunnel Destruction, A State-of-the-Art Summary," WES MP N-78-1, January 1978, U.S. Army Engineer Waterways Experiment Station, Vicksburg, Mississippi.

3. C. H. Dowding and A. Rosen, "Damage to Rock Tunnels from Earthquake Shaking," Journal of the Geotechnical Engineering Division, American Society of Civil Engineers, Vol. 104, No. GT2, February 1978.

4. A. J. Hendron, Jr., "Engineering of Rock Blasting on Civil Projects," "Structural and Geotechnical Mechanics," W. J. Hall, ed., Prentice-Hall, Englewood Cliffs, New Jersey, 1977.

5. U. Langefors, B. Kihlstrom, "The Modern Technique of Rock Blasting," 3rd Edition, John Wiley & Sons, 1978.

APPENDIX A

Shot No. 1

TOTAL CHARGE WEIGHT 31 lbs

Prilled Ammonium Nitrate

VELOCITY- AND DISPLACEMENT-TIME HISTORIES

In the ground motion histories in this Appendix (Figure A.1 through A.18), upward trace deflections indicate upward motions for vertical gages and outward motions for horizontal or radial gages.

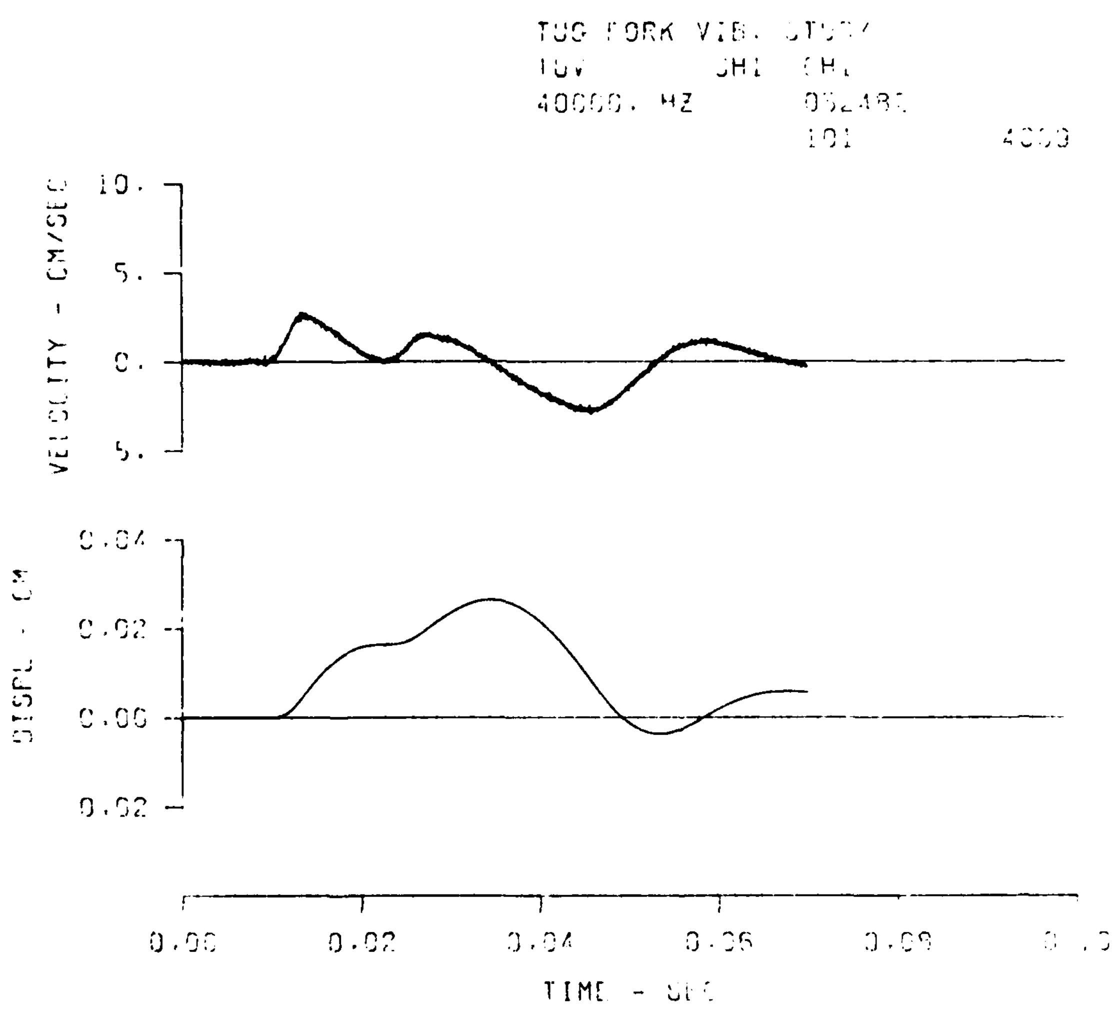

Figure A.1 Vertical particle velocity measurement and integration, gage canister on rock at 40.3 ft slant distance.

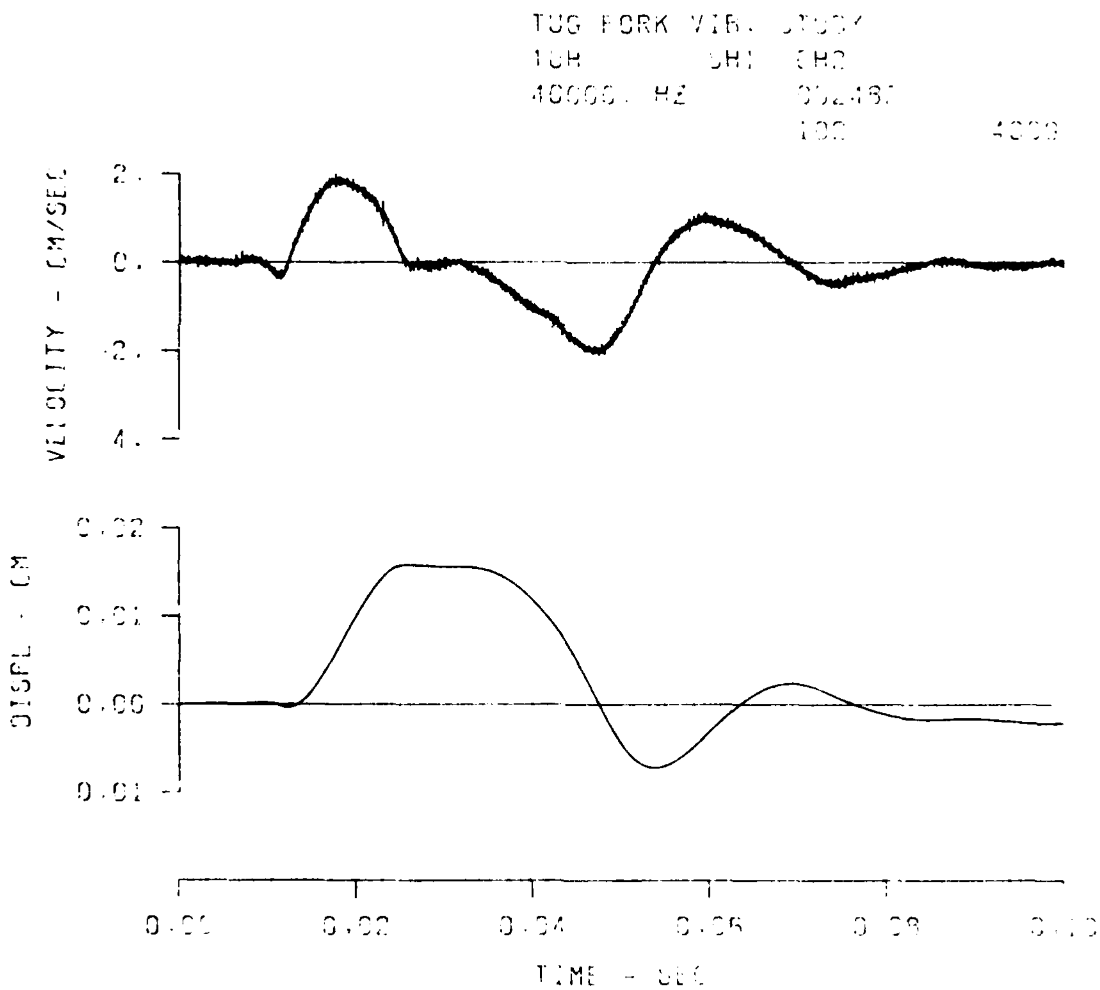

Figure A.2 Horizontal particle velocity measurement and integration, gage canister on rock at 40.3 ft slant distance.

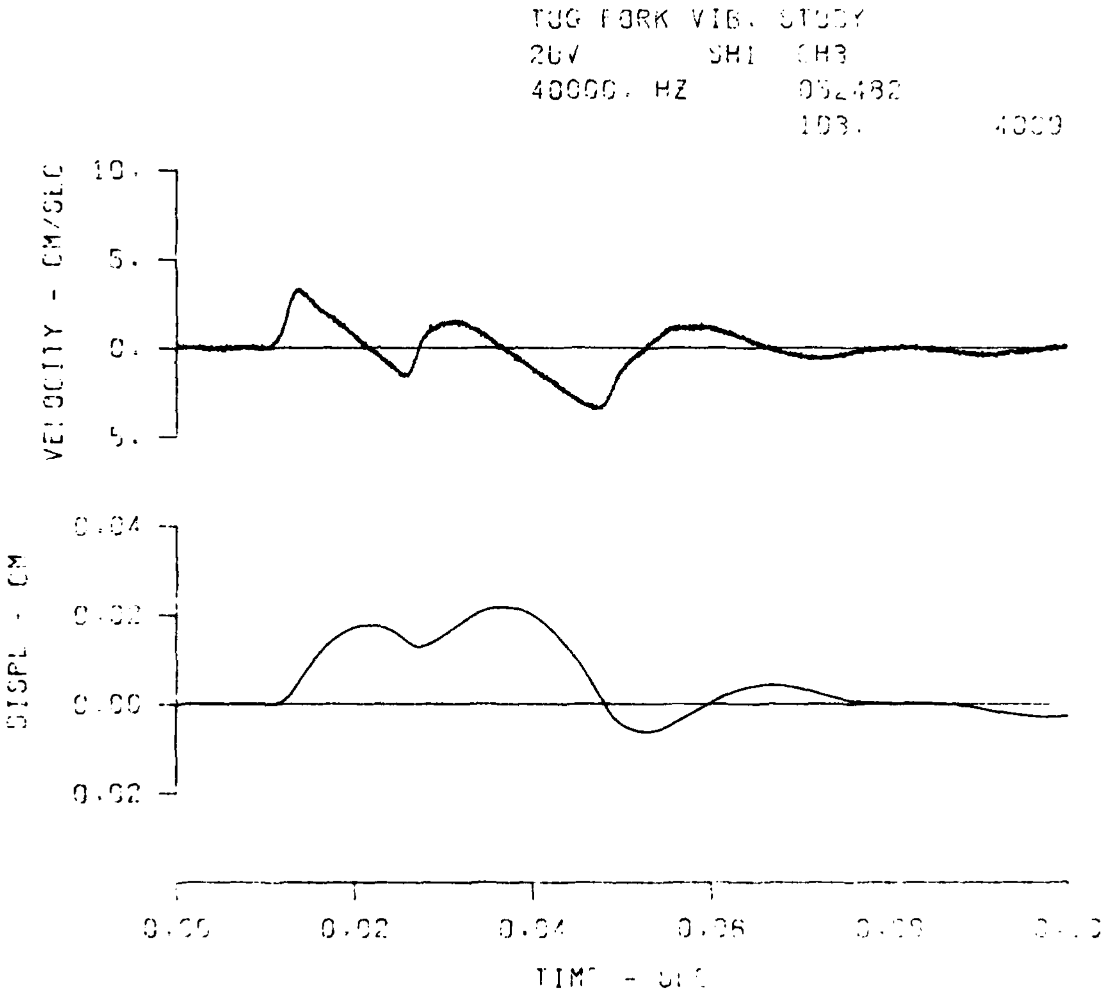

Figure A.3 Vertical particle velocity measurement and integration, gage canister on rock at 42.7 ft slant distance.

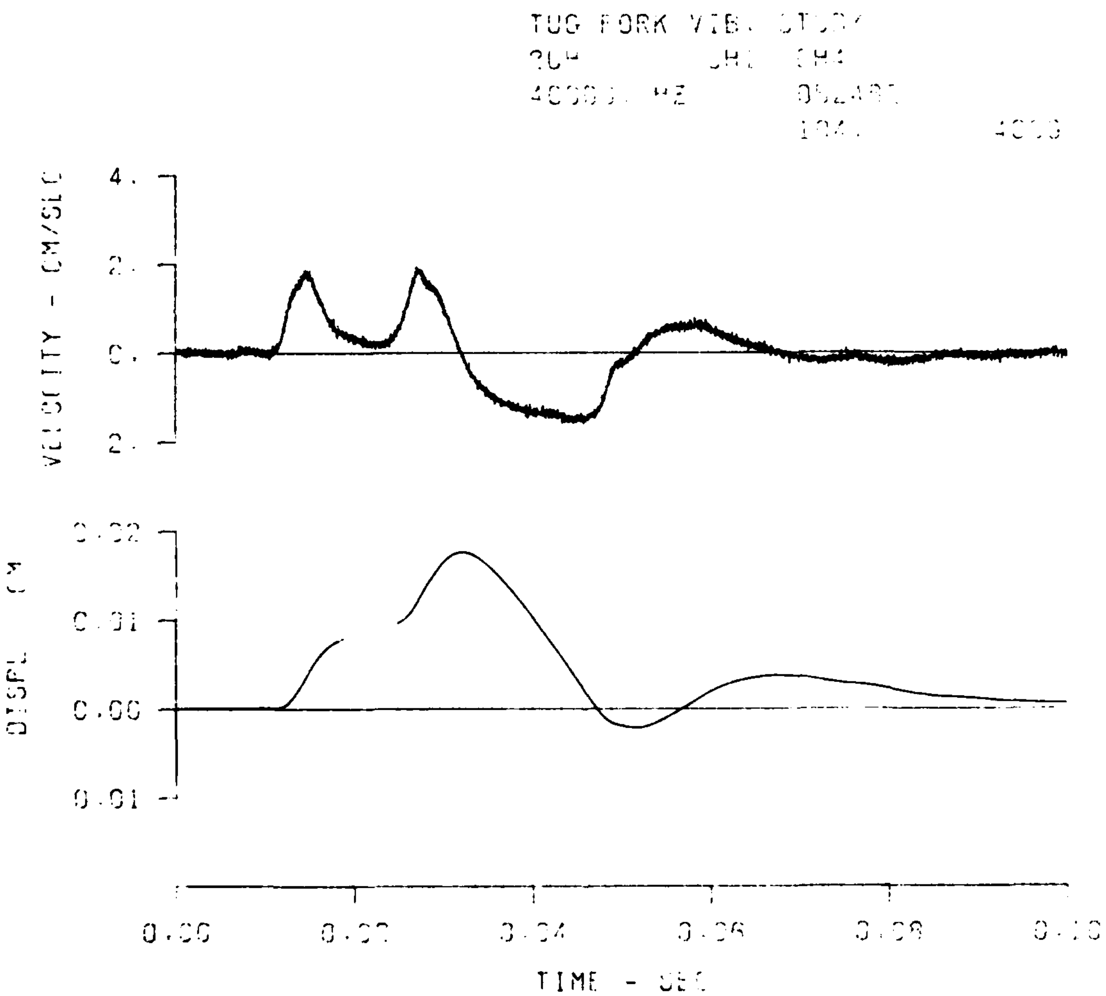

Figure A.4 Horizontal particle velocity measurement and integration, gage canister on rock at 42.7 ft slant distance.

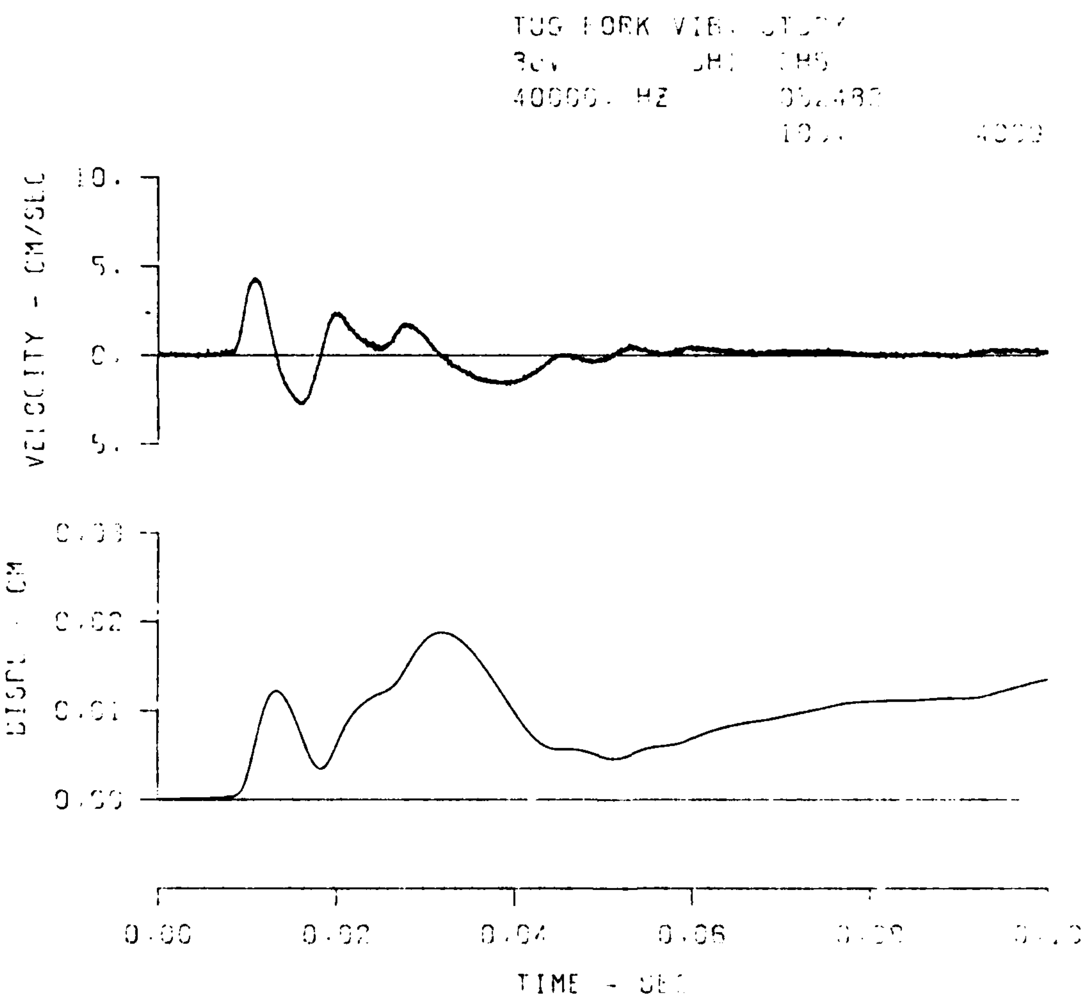

Figure A.5 Vertical particle velocity measurement and integration, gage canister on rock at 44.0 ft slant distance.

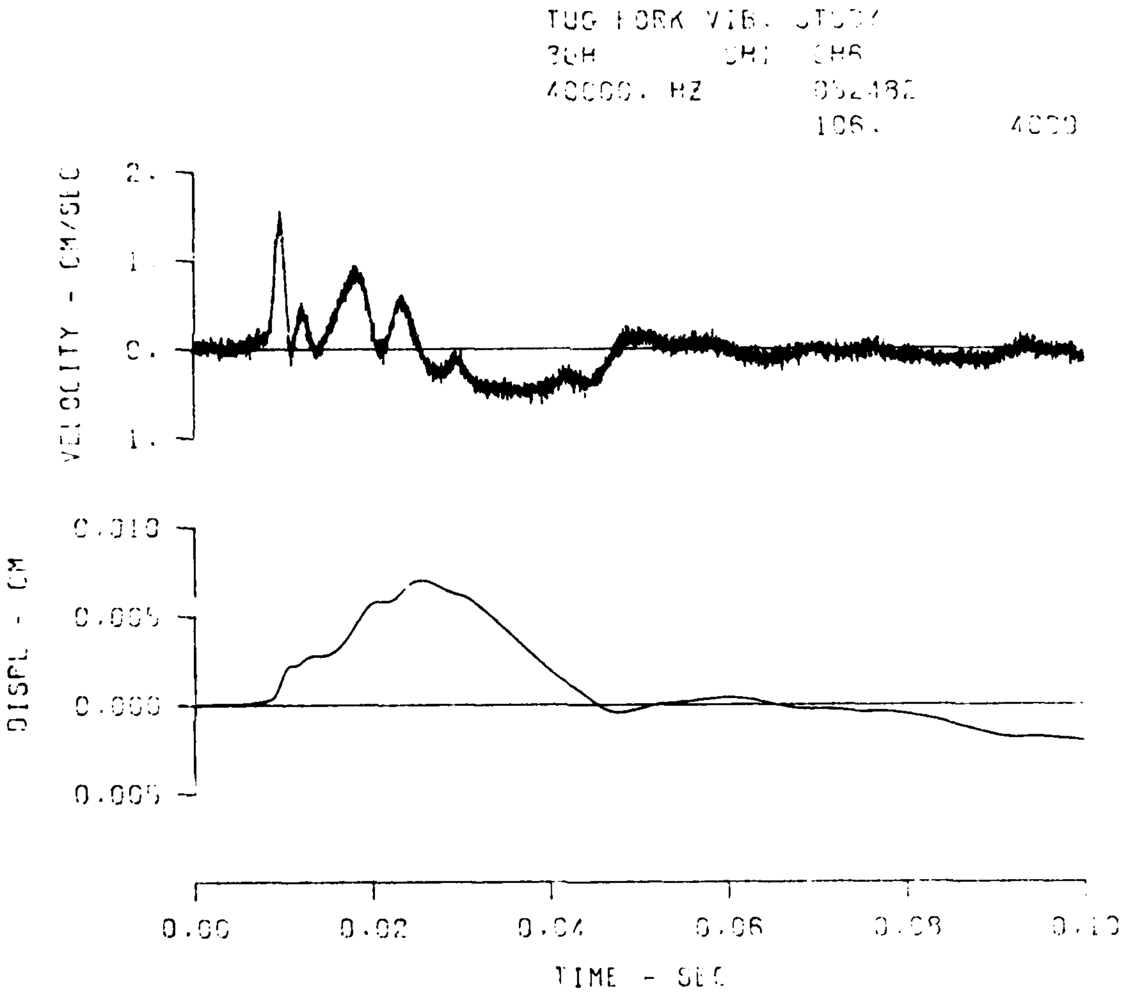

Figure A.6 Horizontal particle velocity measurement and integration, gage canister on rock at 44.0 ft slant distance.

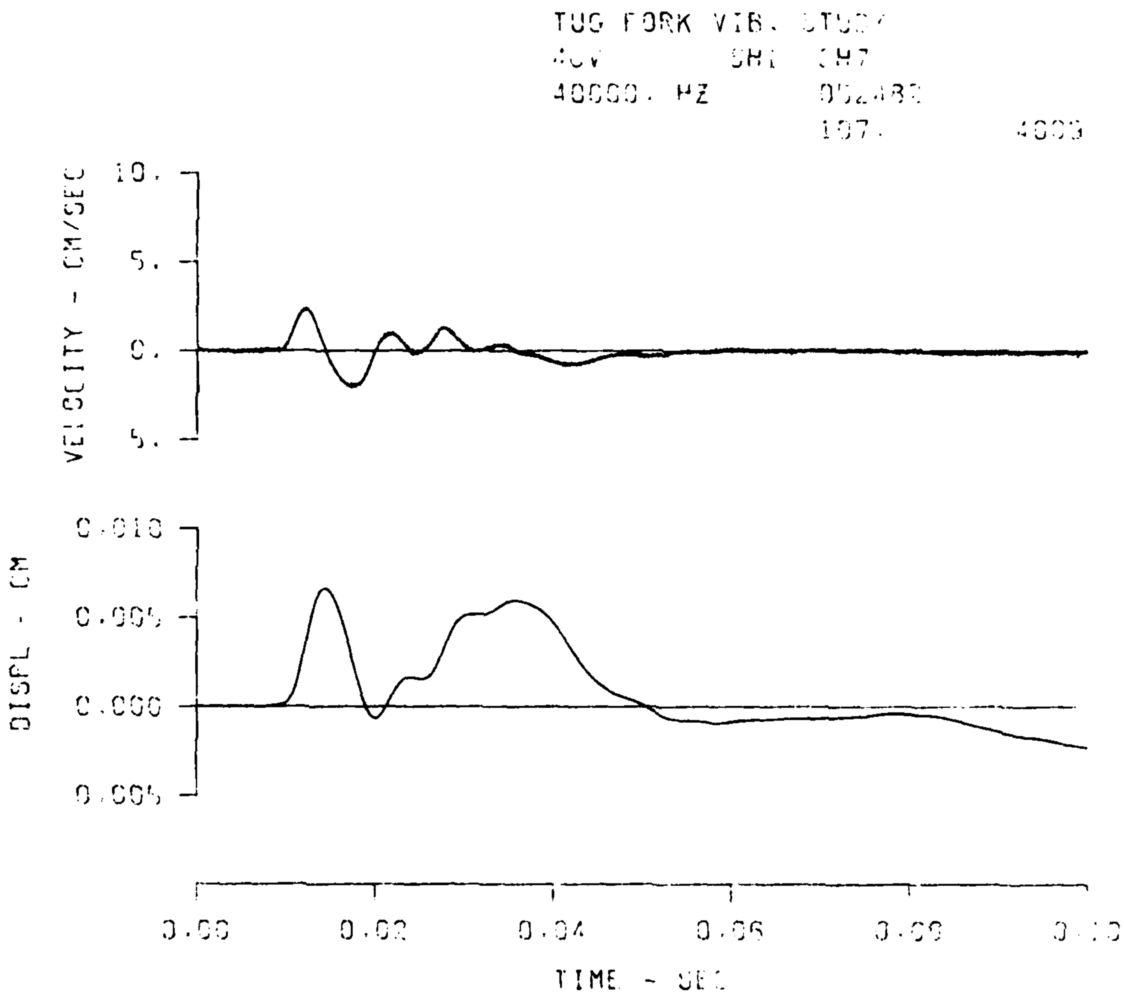

Figure A.7 Vertical particle velocity measurement and integration, gage canister on rock at 54.6 ft slant distance.

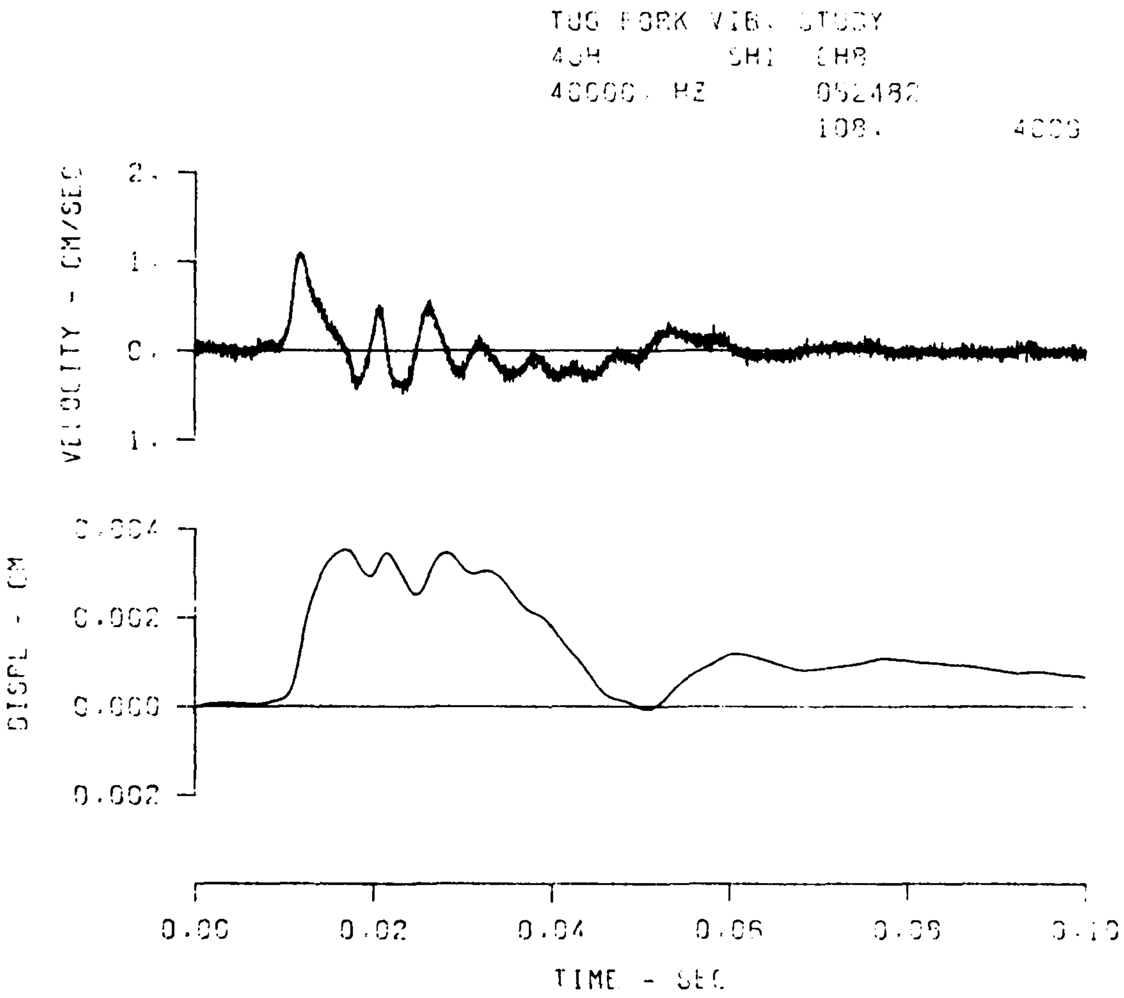

Figure A.8 Horizontal particle velocity measurement and integration, gage canister on rock at 54.6 ft slant distance.

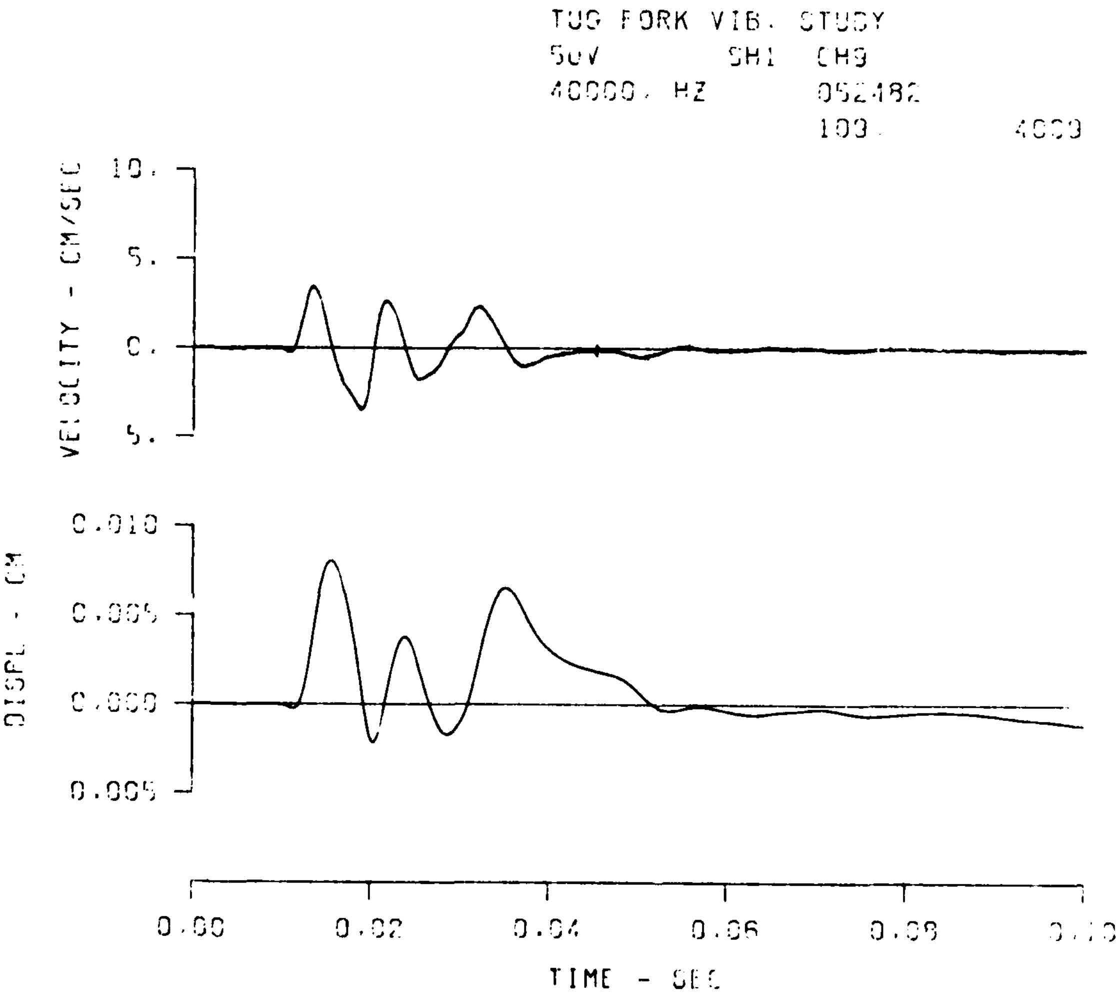

Figure A.9 Vertical particle velocity measurement and integration, gage canister on rock at 66.6 ft slant distance.

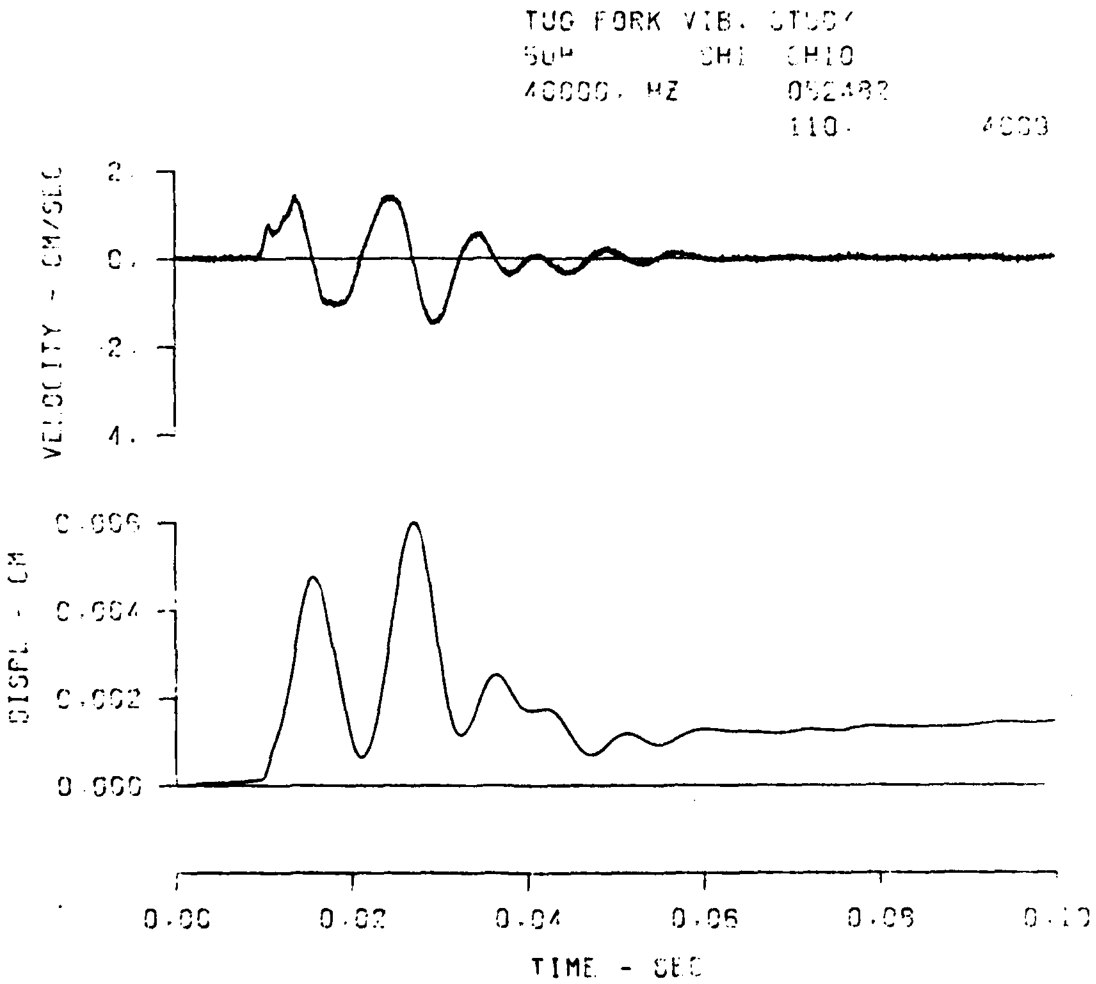

Figure A.10 Horizontal particle velocity measurement and integration, gage canister on rock at 66.6 ft slant distance.

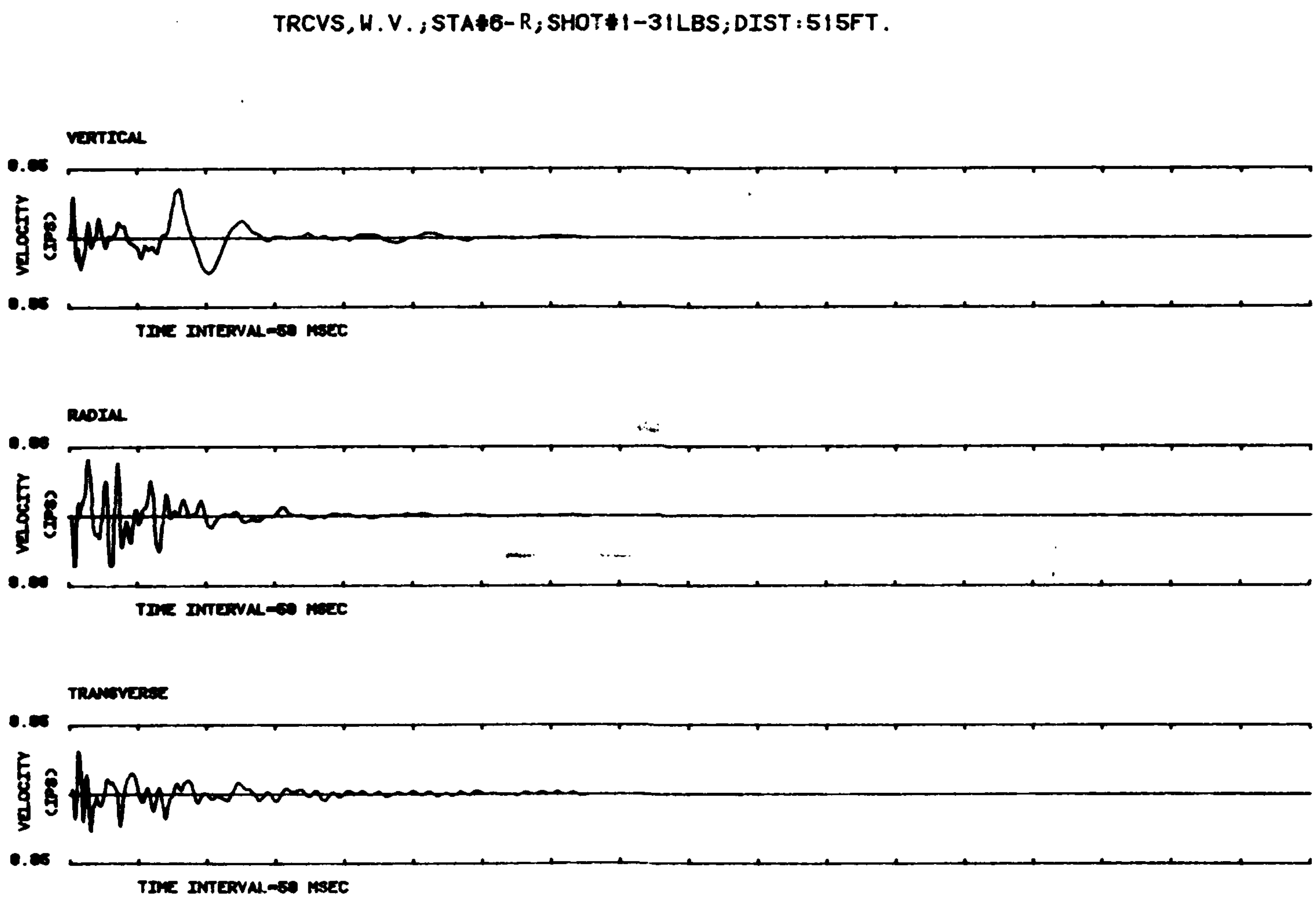

Figure A.11 Vertical, radial and transverse particle velocity measurements, gage canister on rock at 515 ft slant distance.

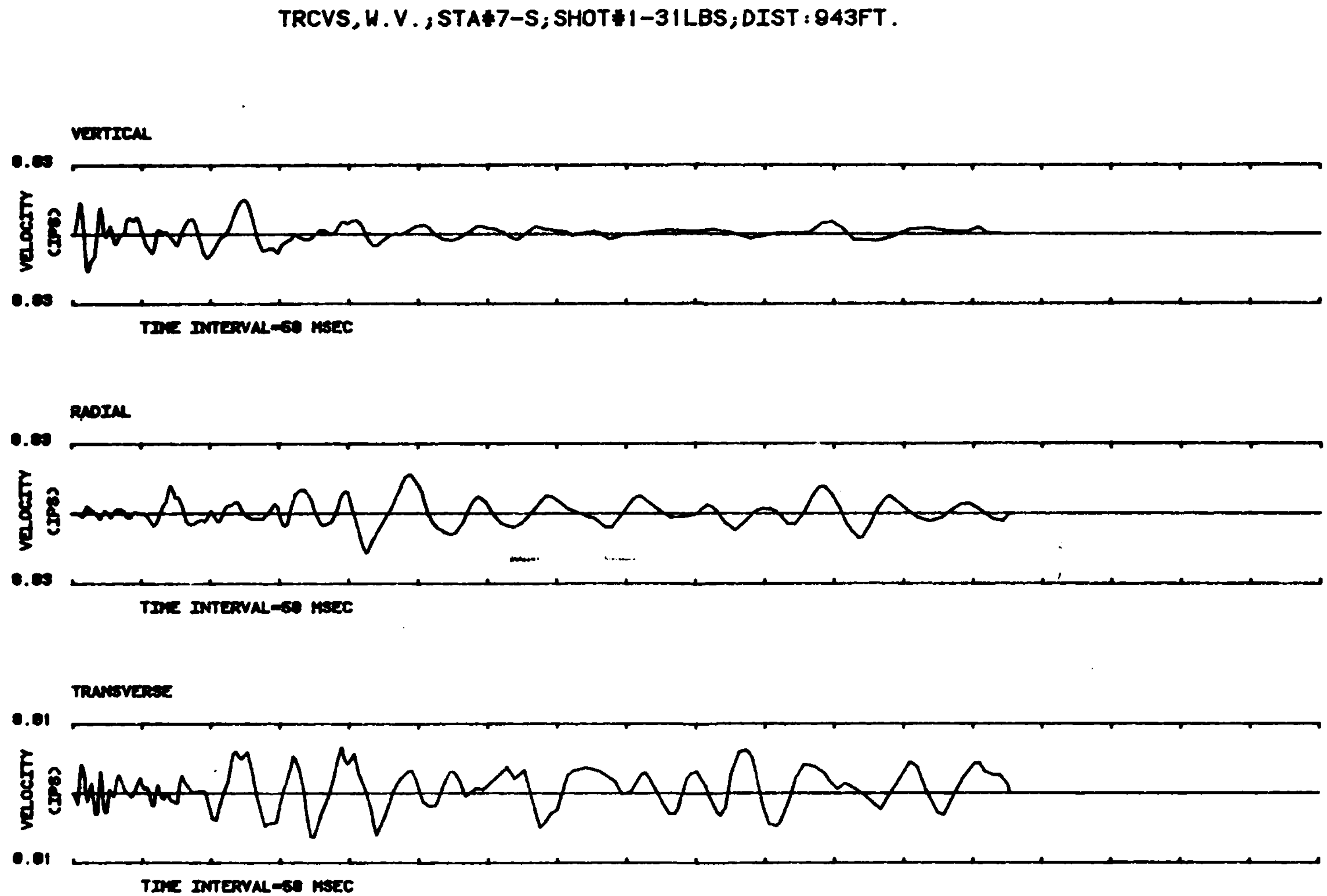

Figure A.12 Vertical, radial and transverse particle velocity measurements, gage canister in soil at 943 ft slant distance.

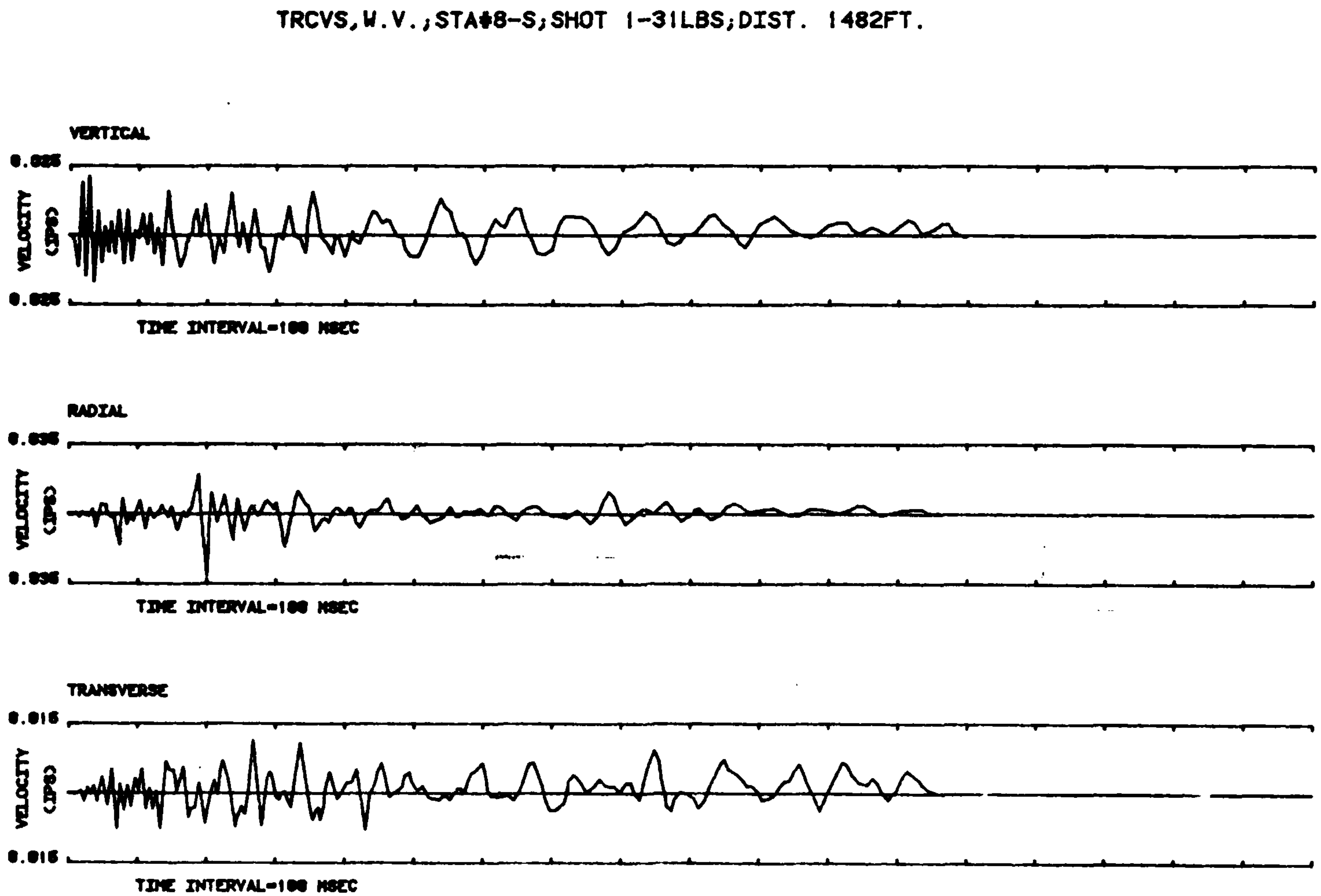

Figure A.13 Vertical, radial and transverse particle velocity measurements, gage canister in soil at 1482 ft slant range.

TRCVS,W.V.;STA#9-S;SHOT 1-31LBS;DIST. 1579FT.

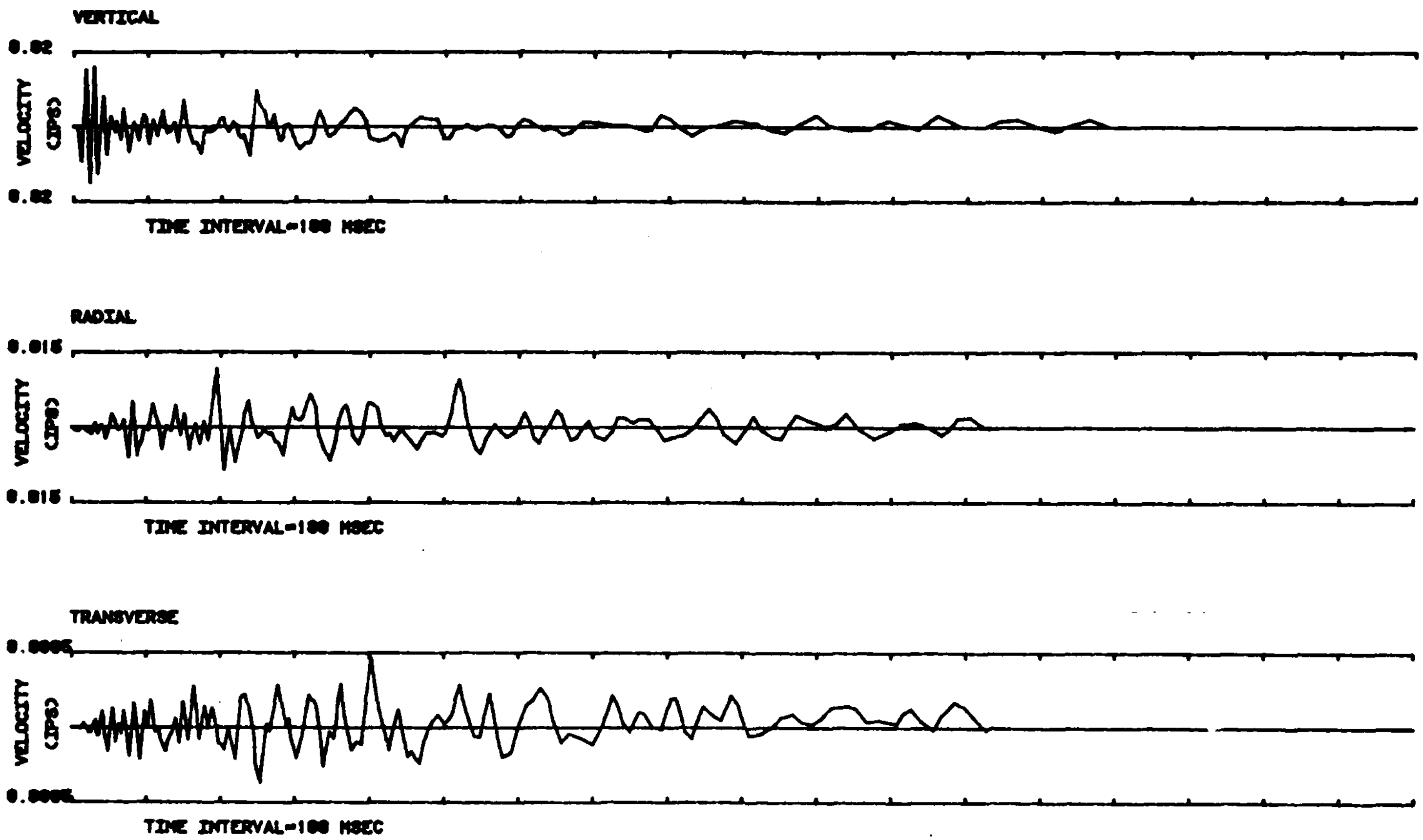

Figure A.14 Vertical, radial and transverse particle velocity measurements, gage canister in soil at 1579 ft slant range.

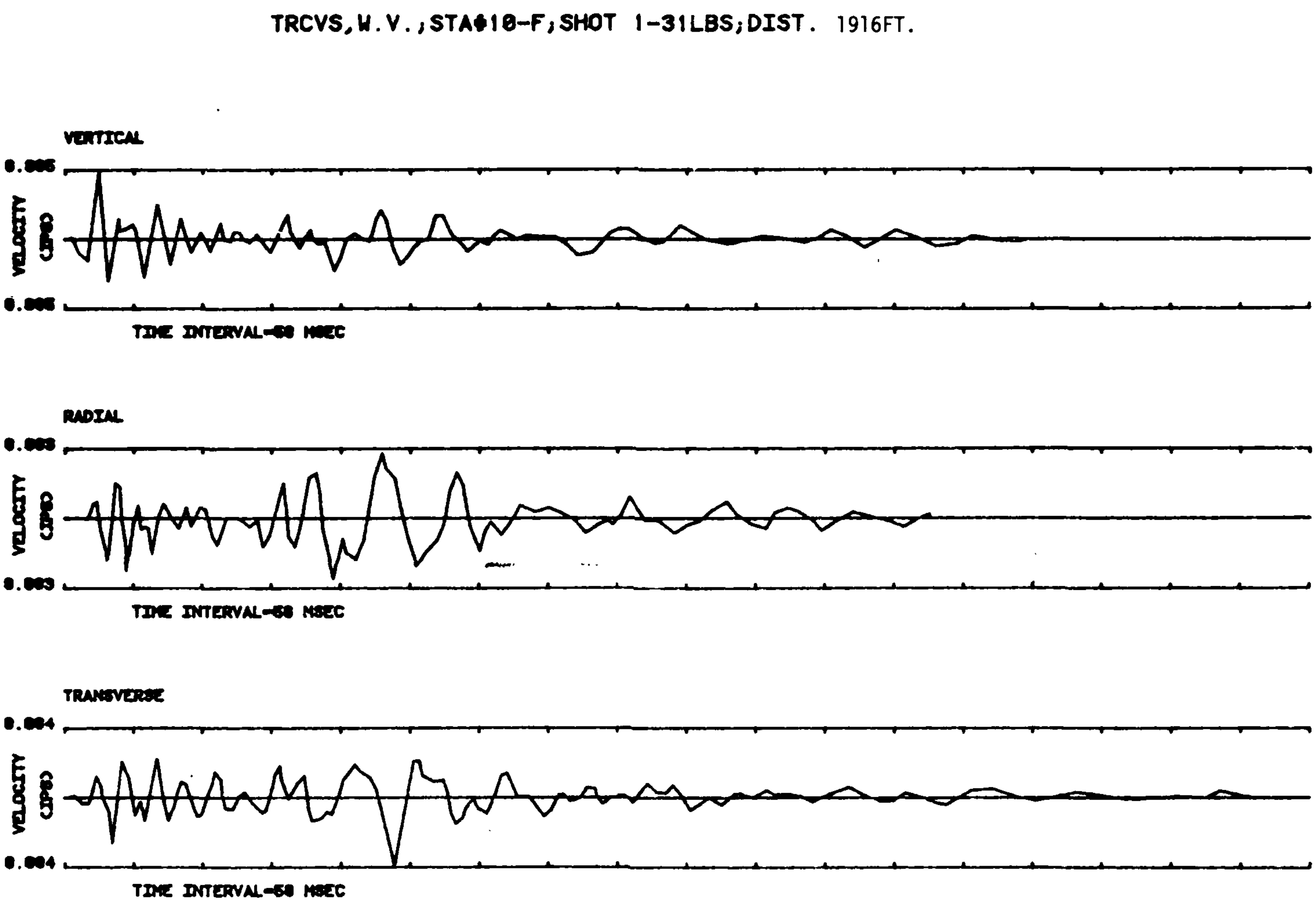

Figure A.15 Vertical, radial and transverse particle velocity measurements, gage canister on concrete slab (rock) at 1916 ft slant distance.

TRCVS,W.V.;STA#11-R;SHOT 1-31LBS;DIST. 1918FT.

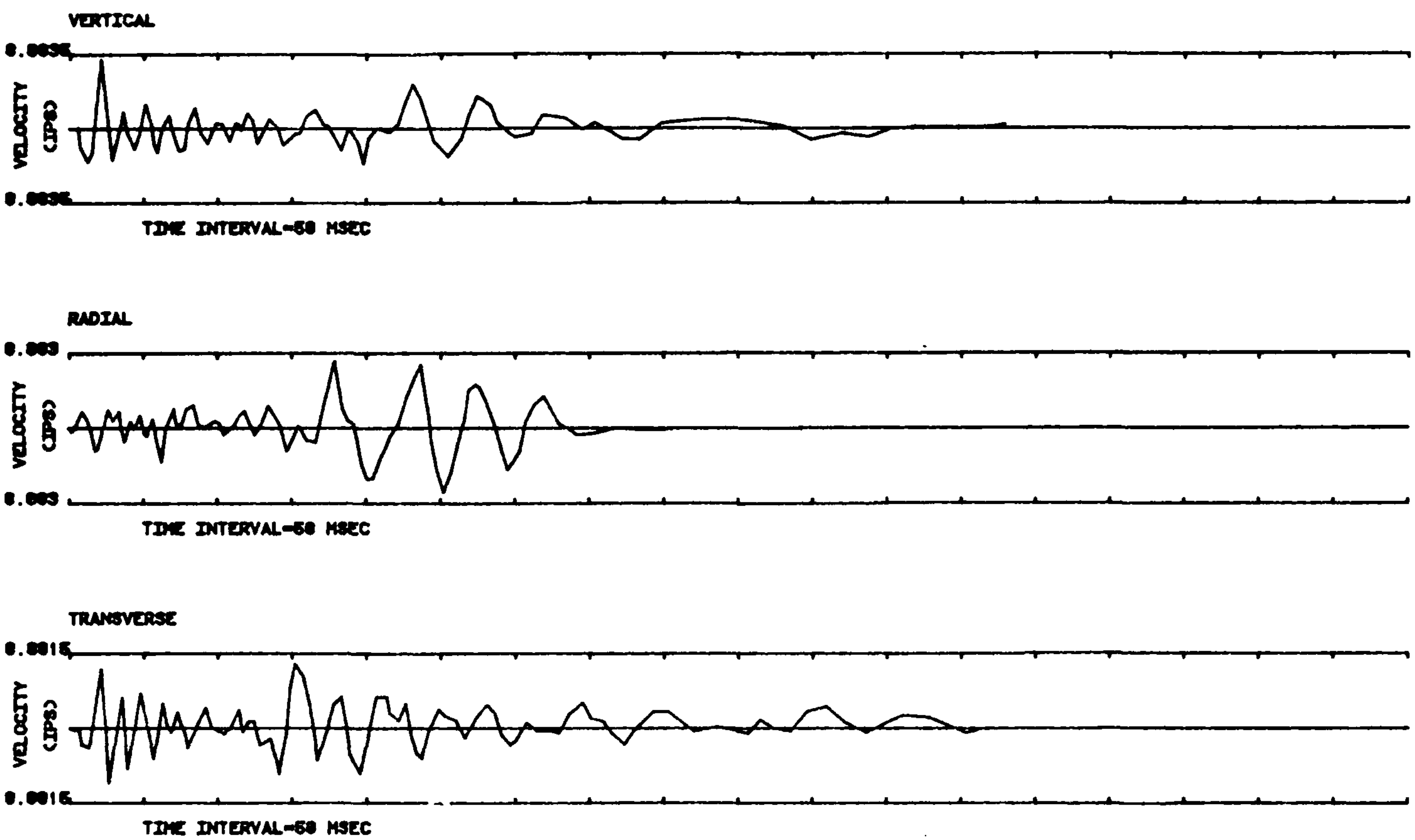

Figure A.16 Vertical, radial and transverse particle velocity measurements, gage canister on rock at 1918 ft slant distance.

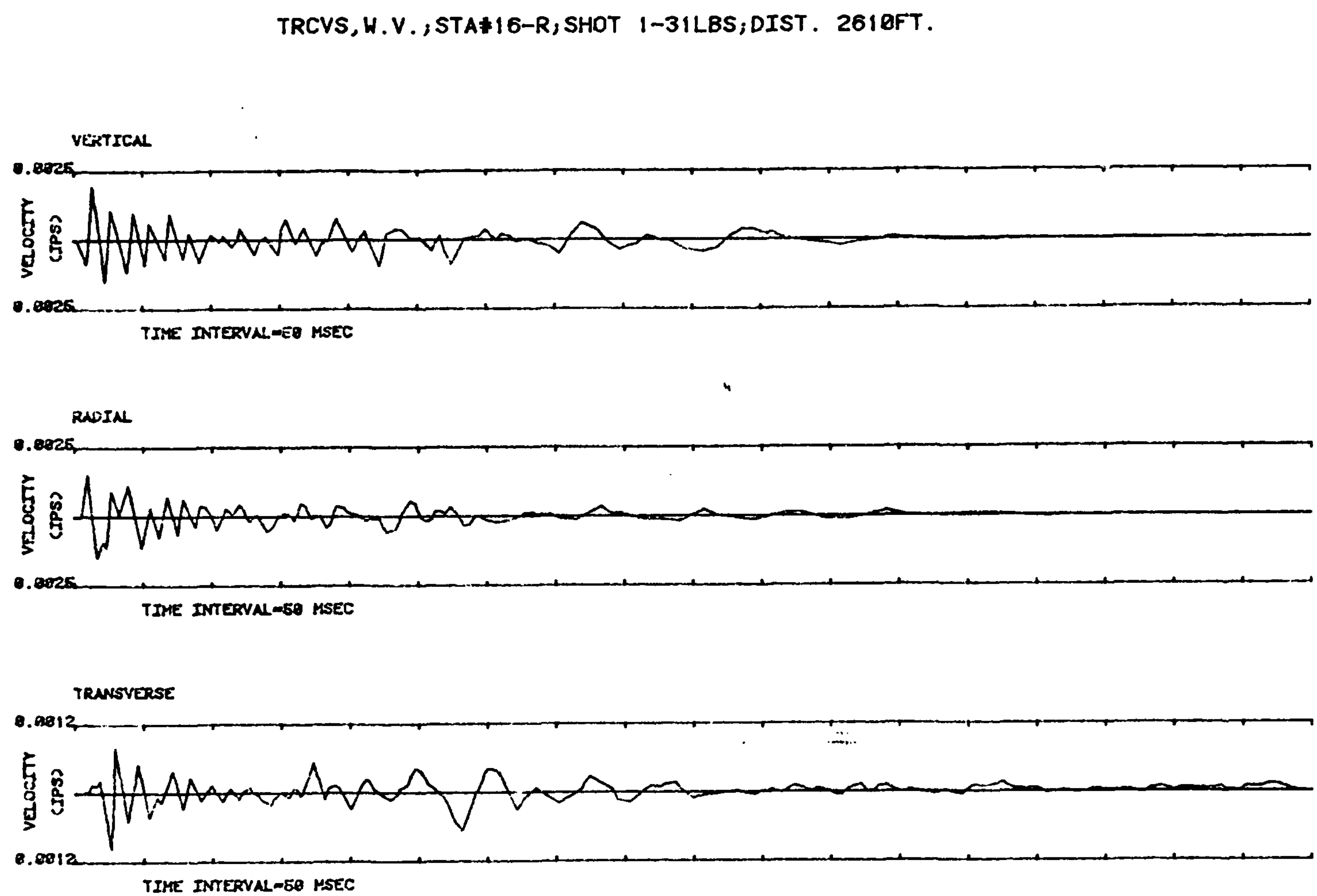

Figure A.17 Vertical, radial and transverse particle velocity measurements, gage canister on tunnel liner (rock) at 2610 ft slant distance.

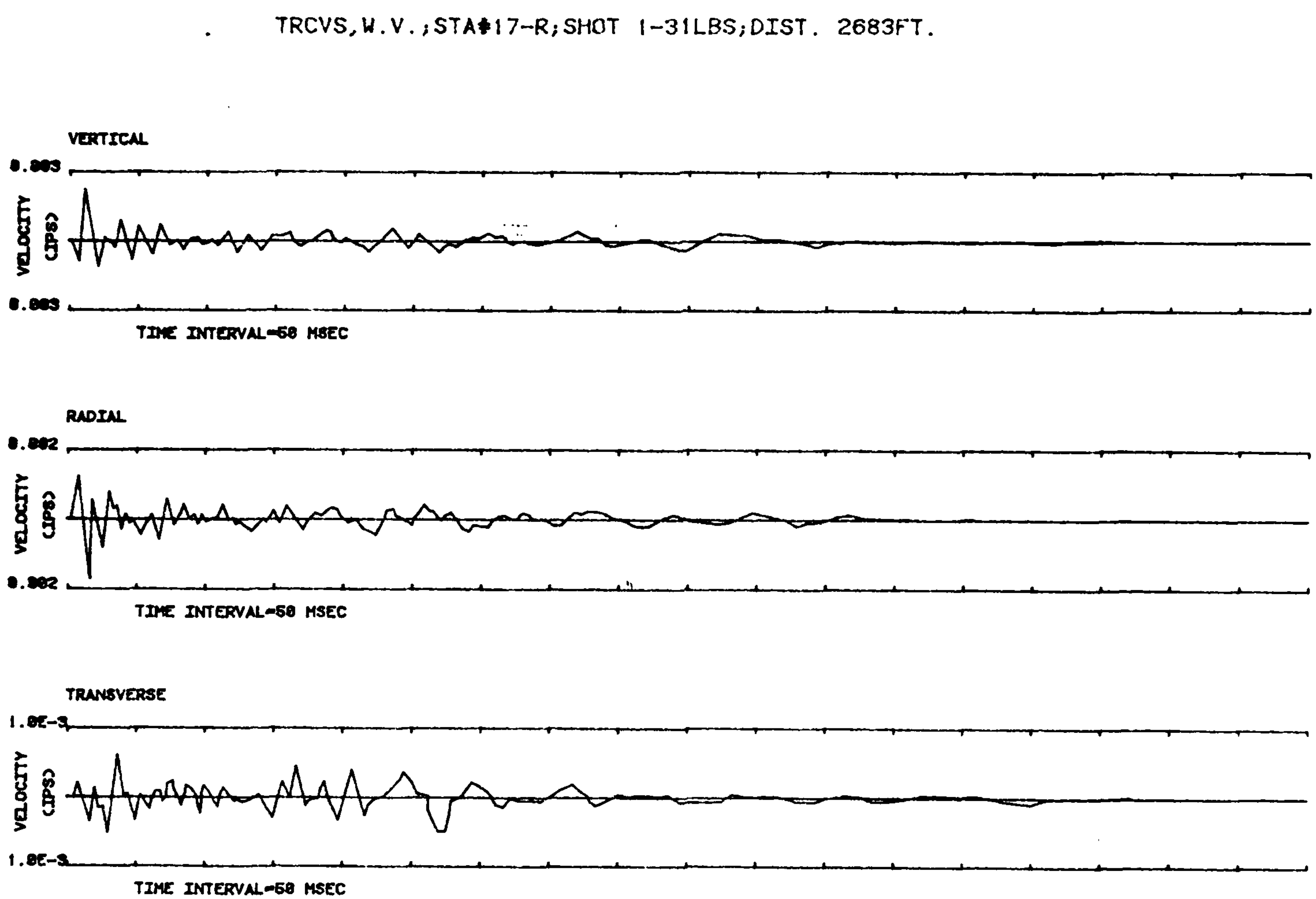

Figure A.18 Vertical, radial and transverse particle velocity measurements, gage canister in unlined tunnel (rock) at 2683 ft slant distance.

APPENDIX B

Shot No. 2

TOTAL CHARGE WEIGHT 104 lb

Prilled Ammonium Nitrate

VELOCITY- AND DISPLACEMENT-TIME HISTORIES

In the ground motion histories in this Appendix (Figures B.1 through B.18), upward trace deflections indicate upward motions for vertical gages and outward motions for horizontal or radial gages.

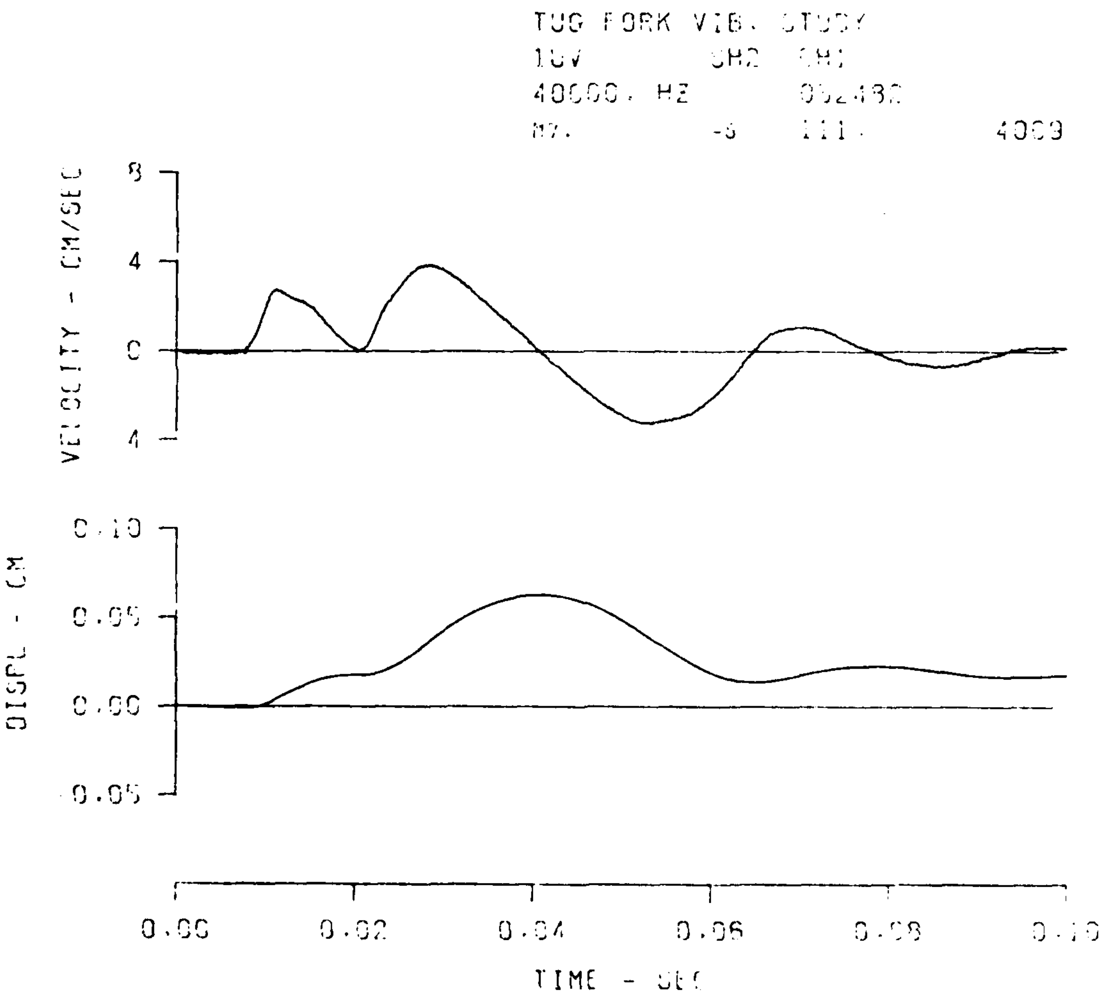

Figure B.1 Vertical particle velocity measurement and integration, gage canister on rock at 47.0 ft slant distance.

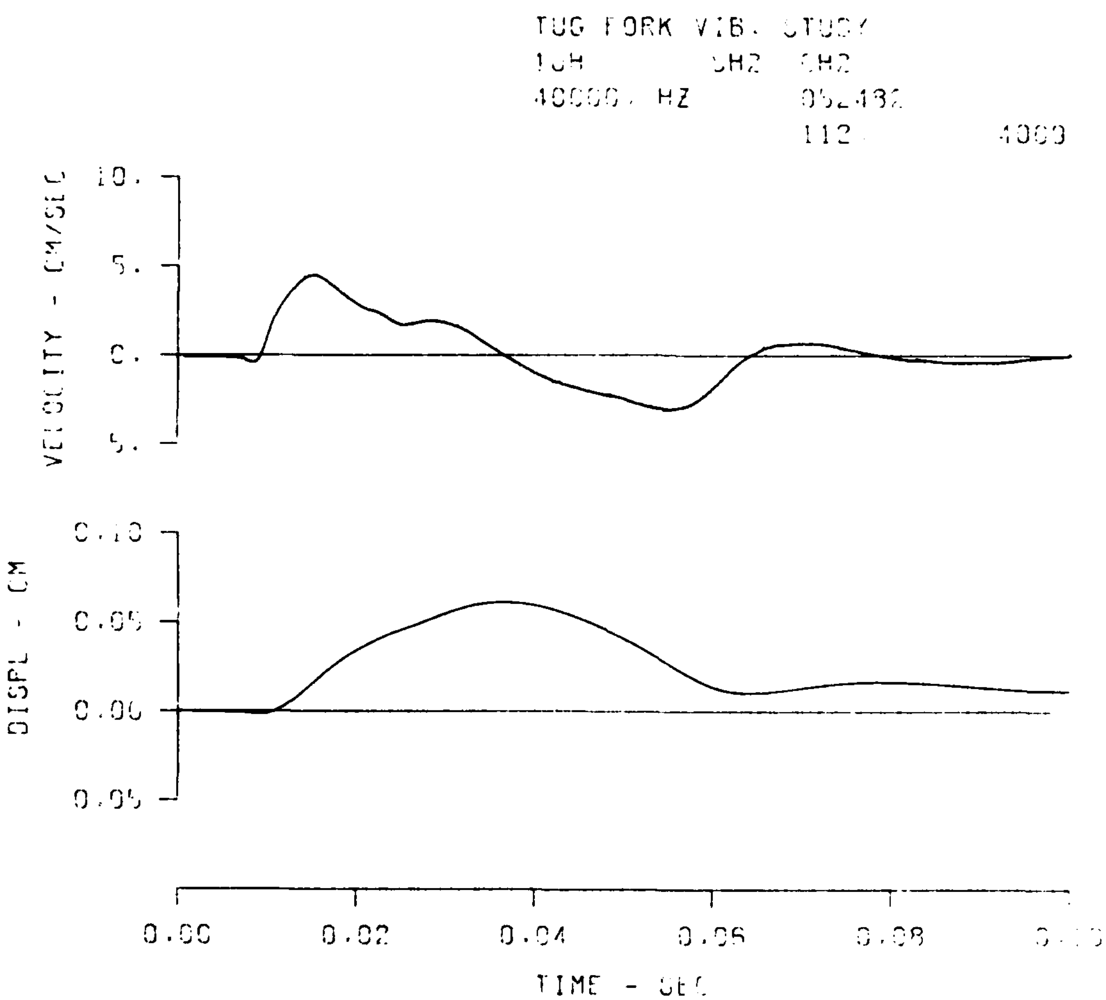

Figure B.2 Horizontal particle velocity measurement and integration, gage canister on rock at 47.0 ft slant distance.

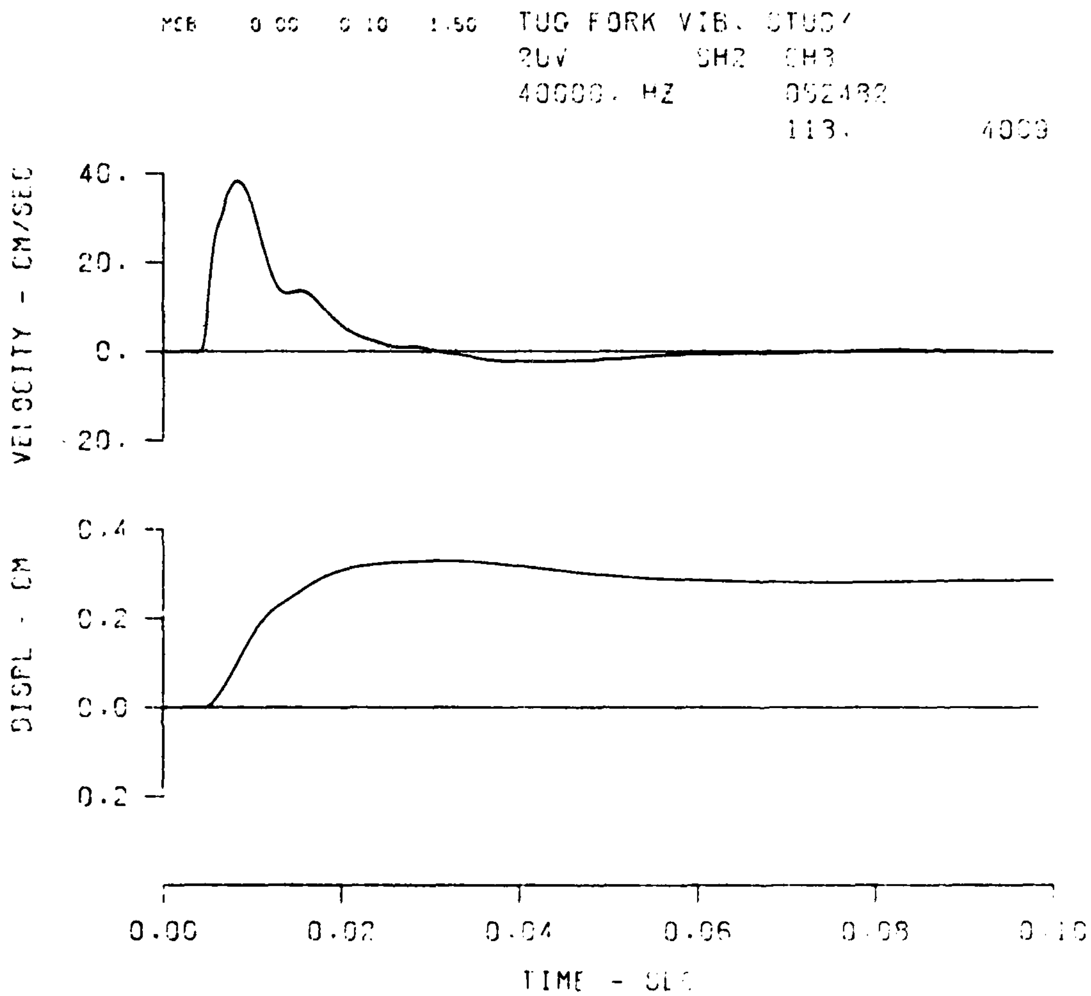

Figure B.3 Vertical particle velocity measurement and integration, gage canister on rock at 31.3 ft slant distance.

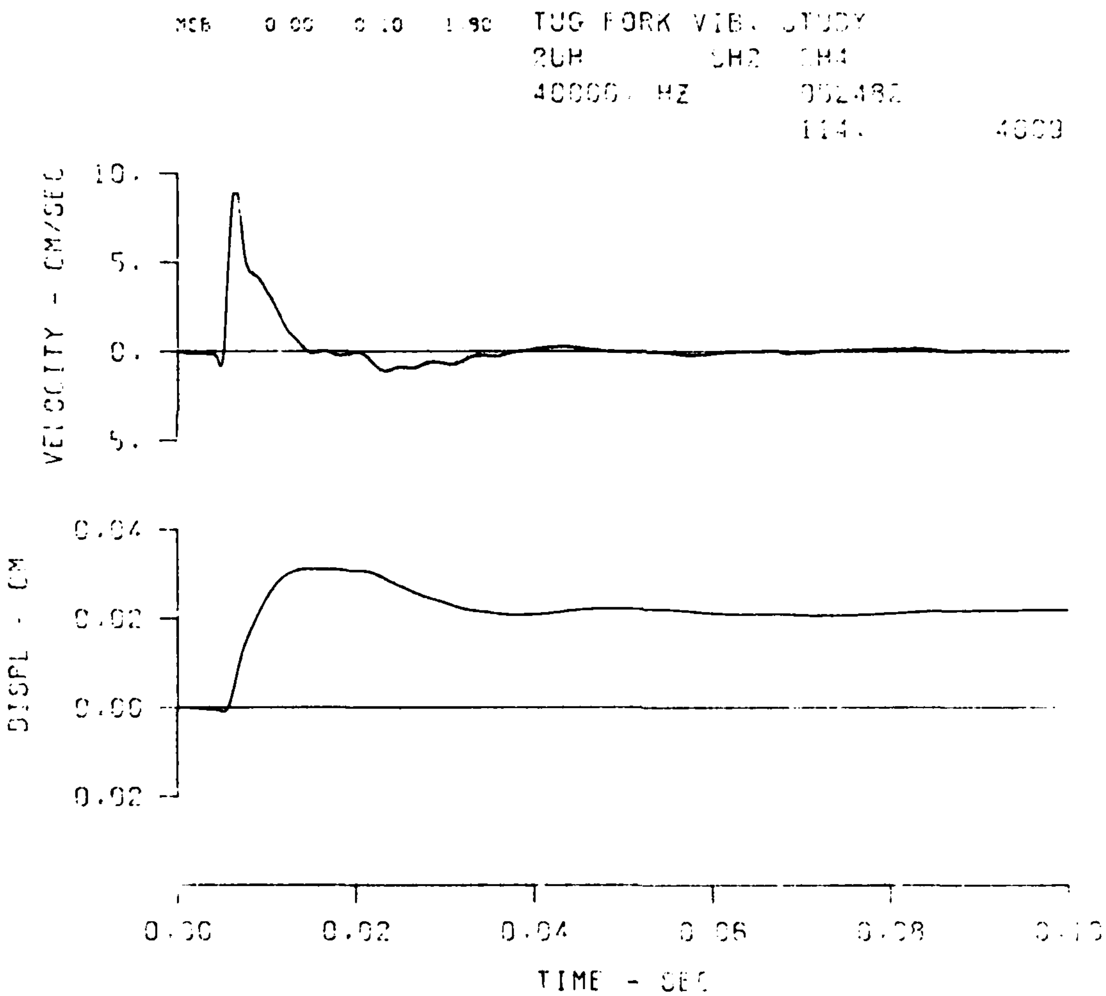

Figure B.4 Horizontal particle velocity measurement and integration, gage canister on rock at 31.3 ft slant distance.

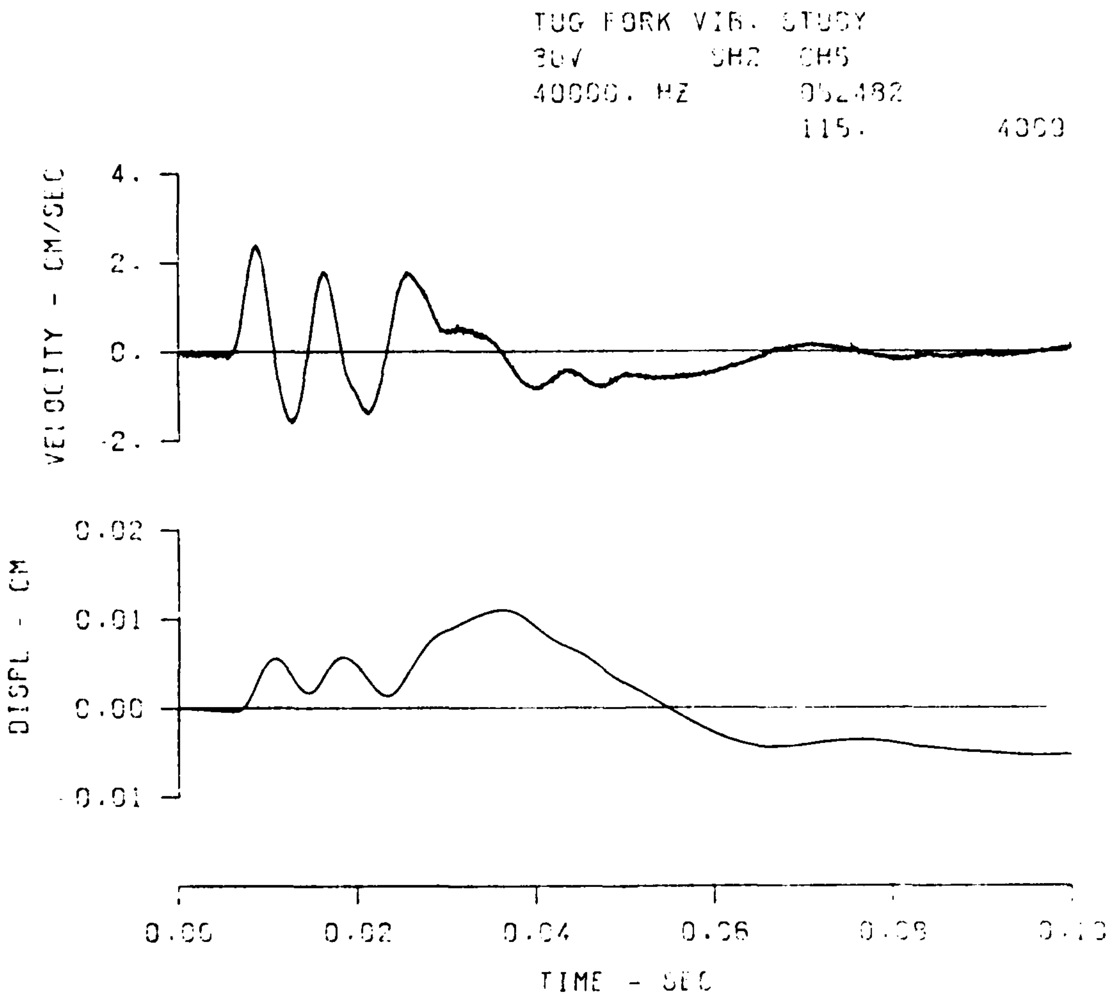

Figure B.5 Vertical particle velocity measurement and integration, gage canister on rock at 58.4 ft slant distance.

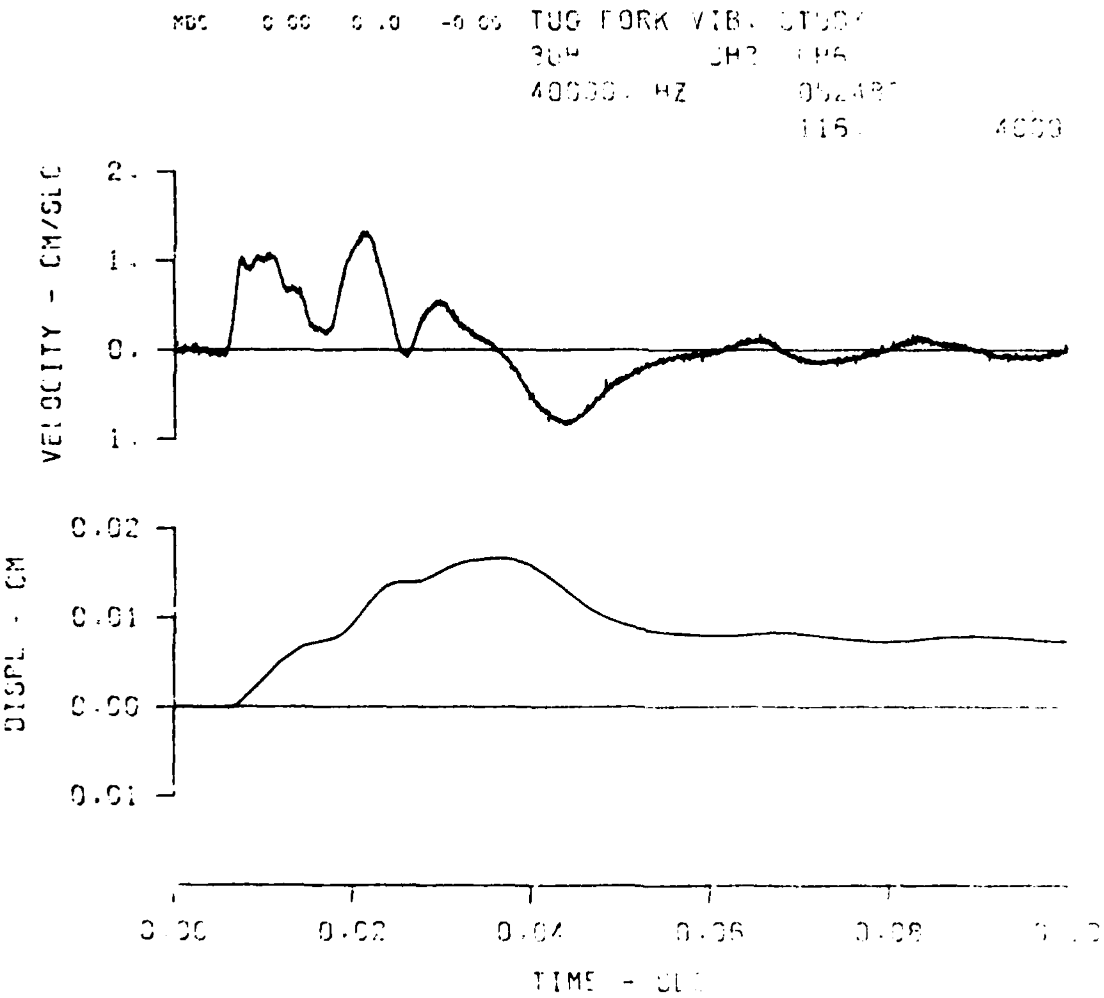

Figure B.6 Horizontal particle velocity measurement and integration, gage canister on rock at 58.4 ft slant distance.

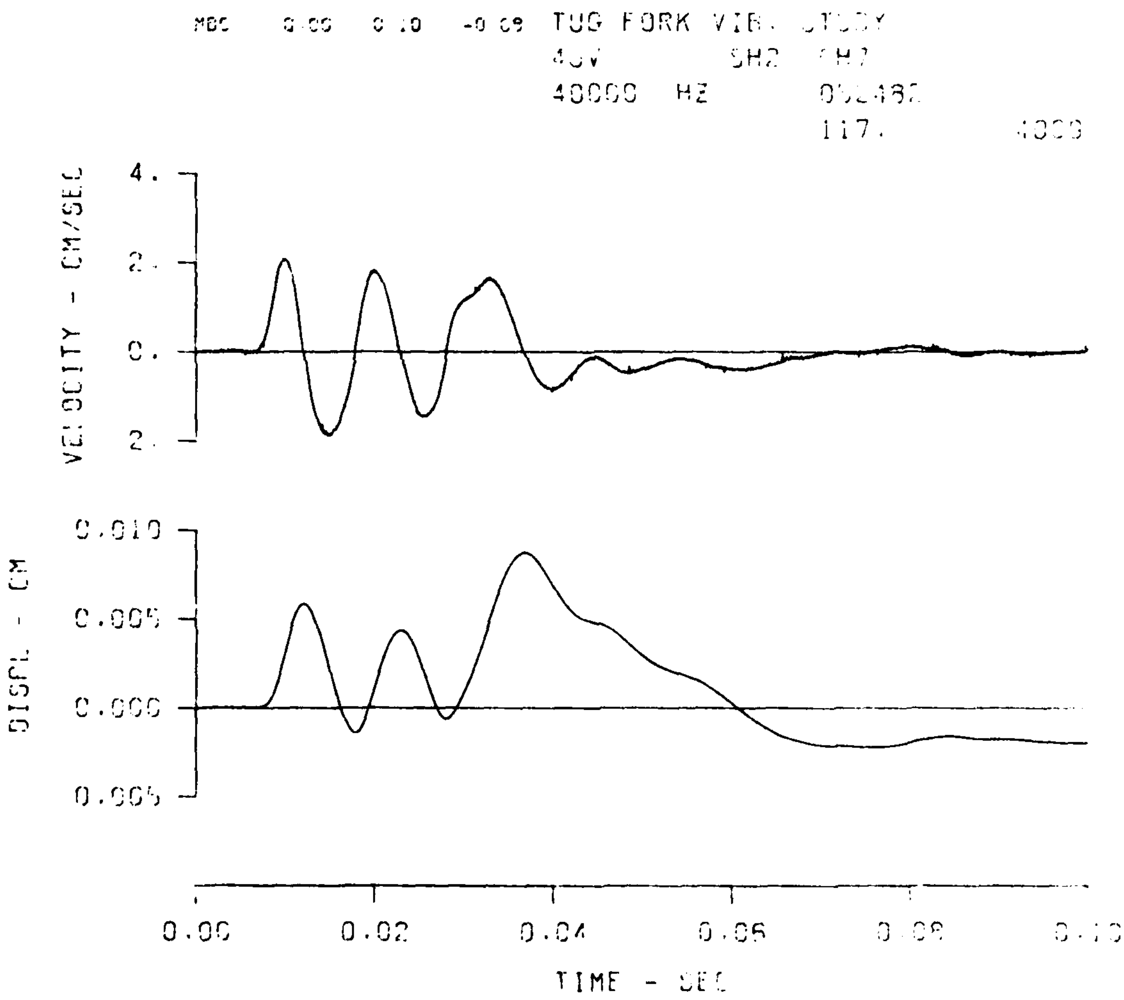

Figure B.7 Vertical particle velocity measurement and integration, gage canister on rock at 73.2 ft slant distance.

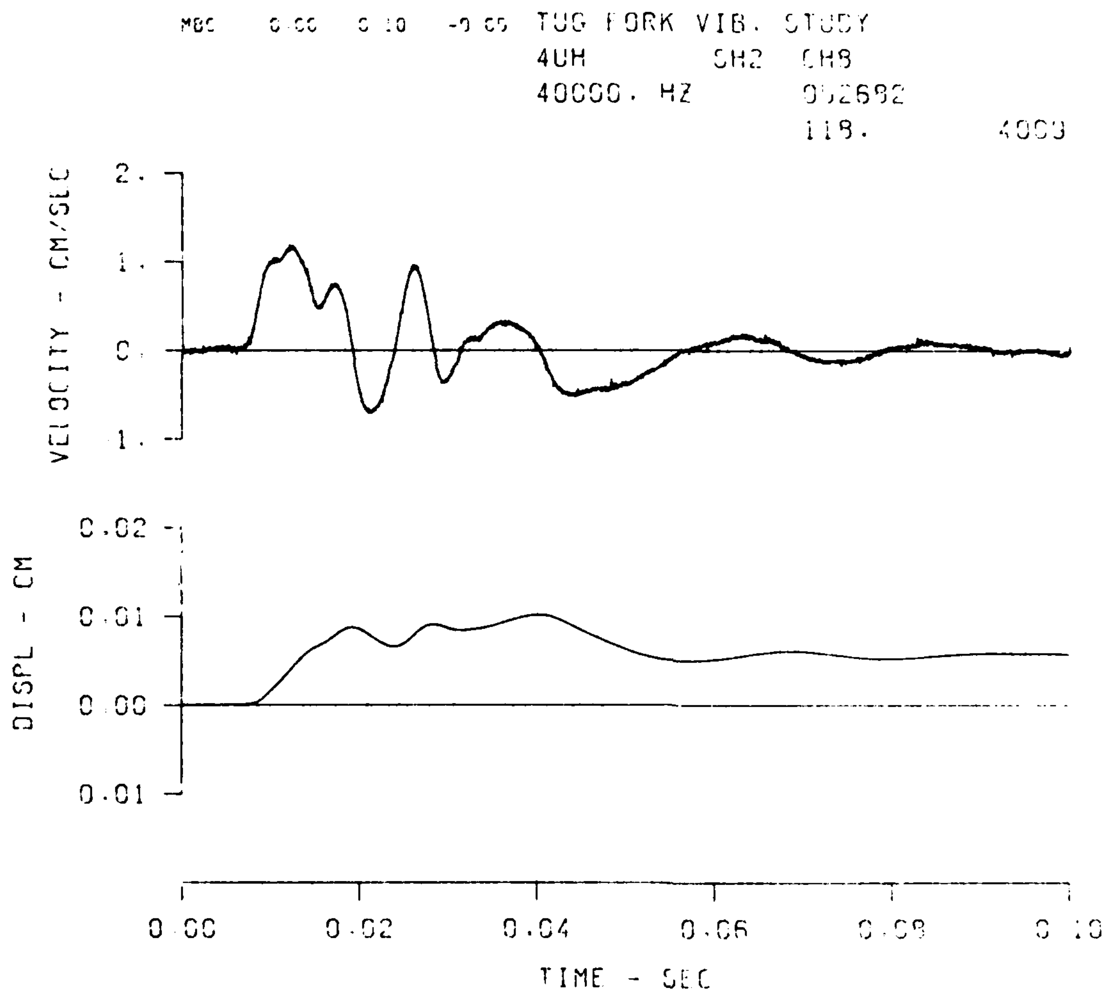

Figure B.8 Horizontal particle velocity measurement and integration, gage canister on rock at 73.2 ft slant distance.

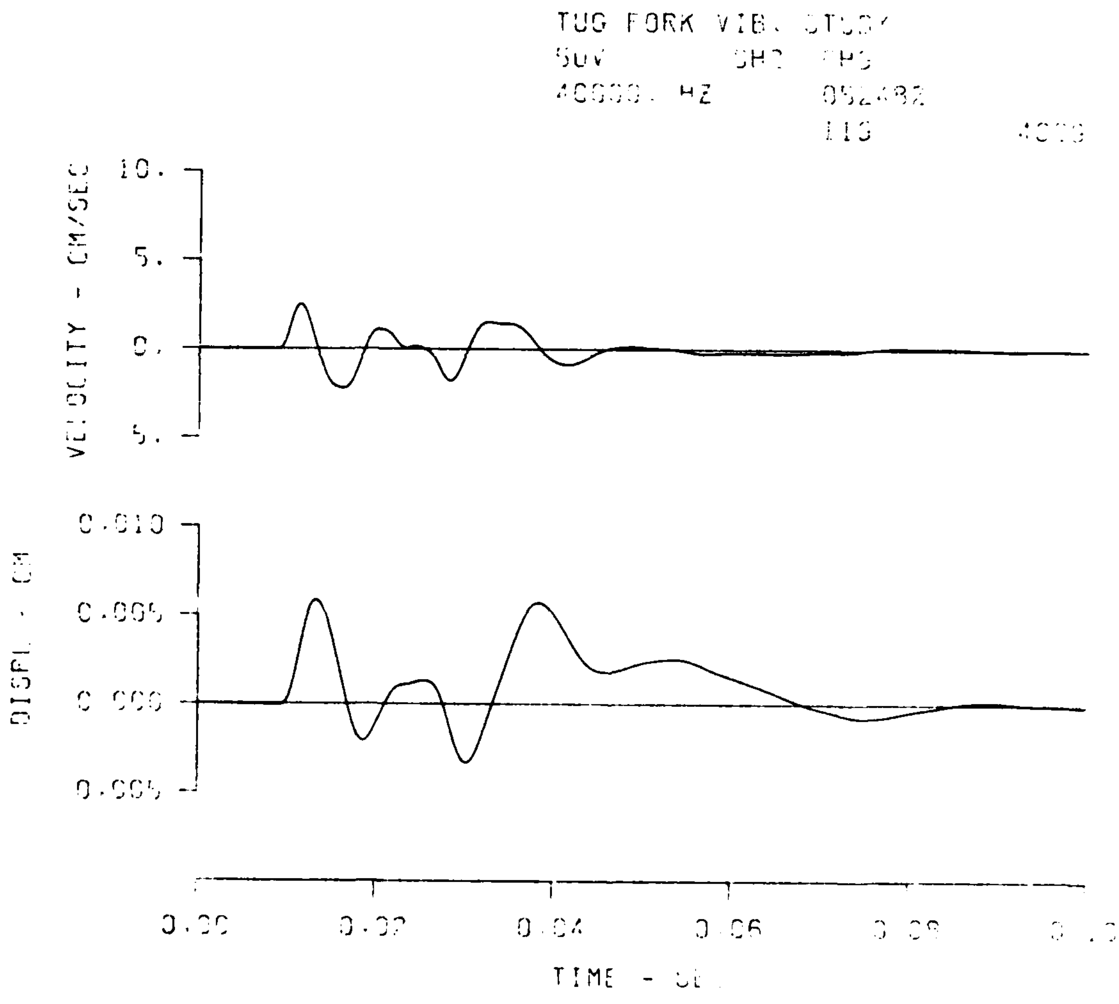

Figure B.9 Vertical particle velocity measurement and integration, gage canister on rock at 88.7 ft slant distance.

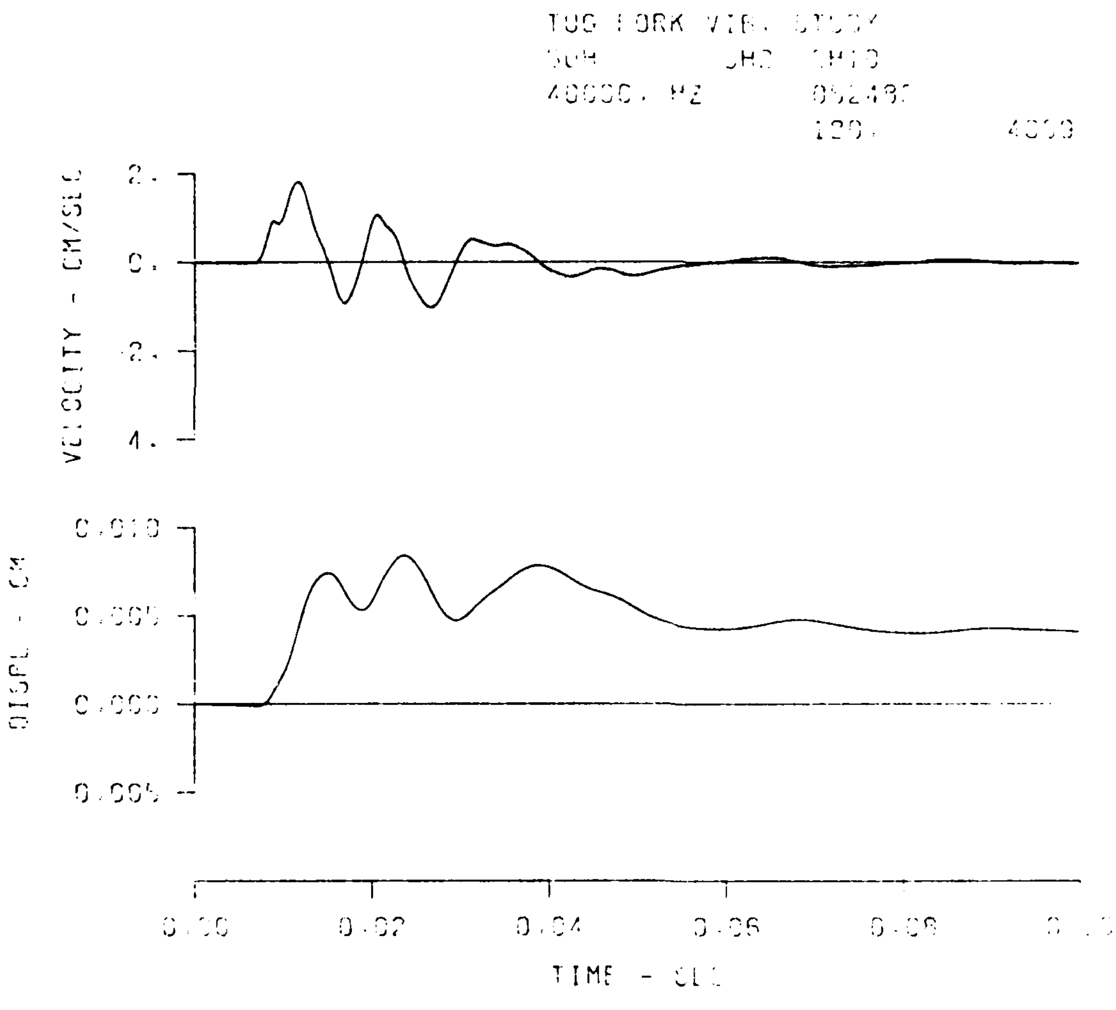

Figure B.10 Horizontal particle velocity measurement and integration, gage canister on rock at 88.7 ft slant distance.

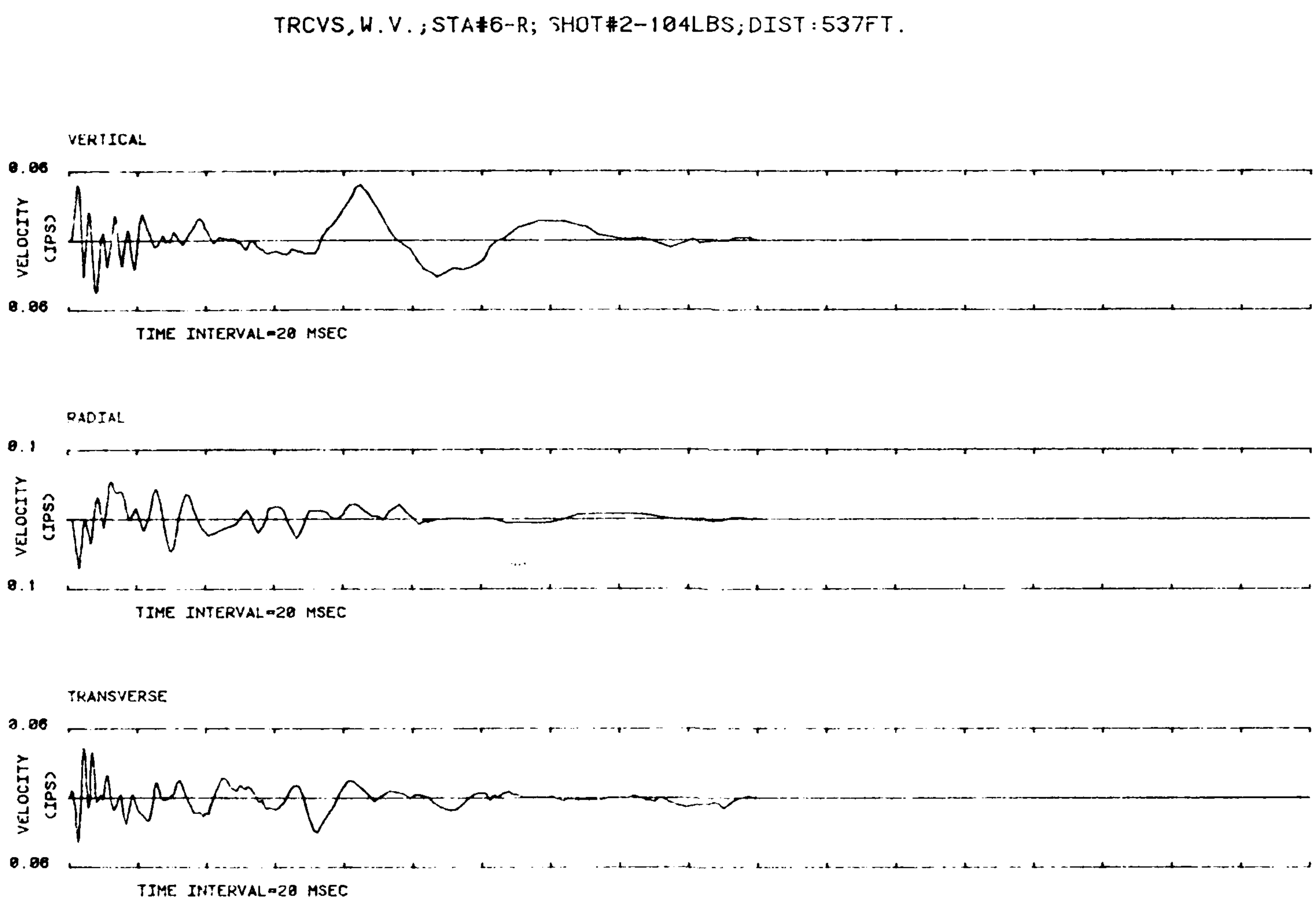

Figure B.11 Vertical, radial and transverse particle velocity measurements, gage canister on rock at 537 ft slant distance.

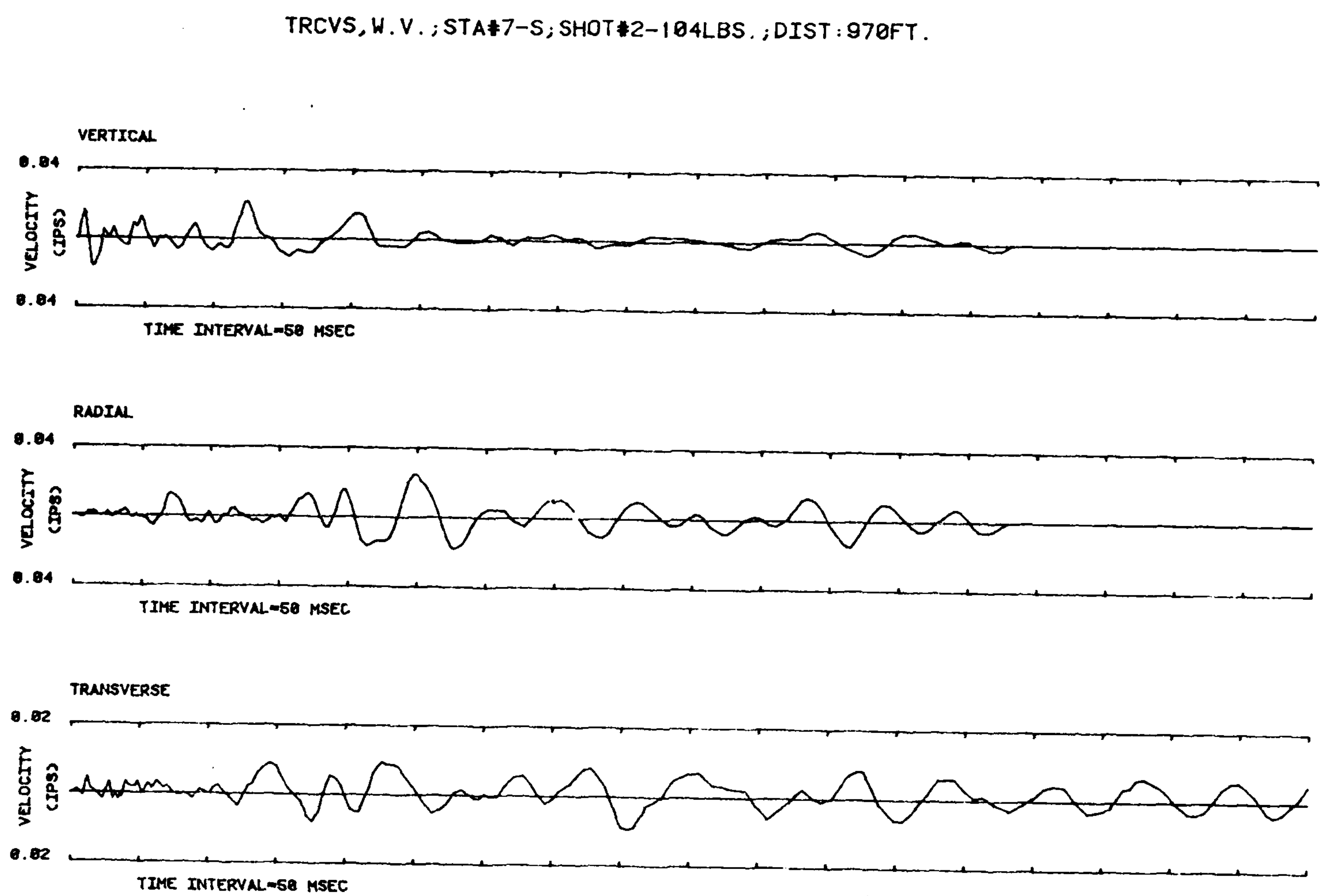

Figure B.12 Vertical, radial and transverse particle velocity measurements, gage canister in soil at 970 ft slant distance.

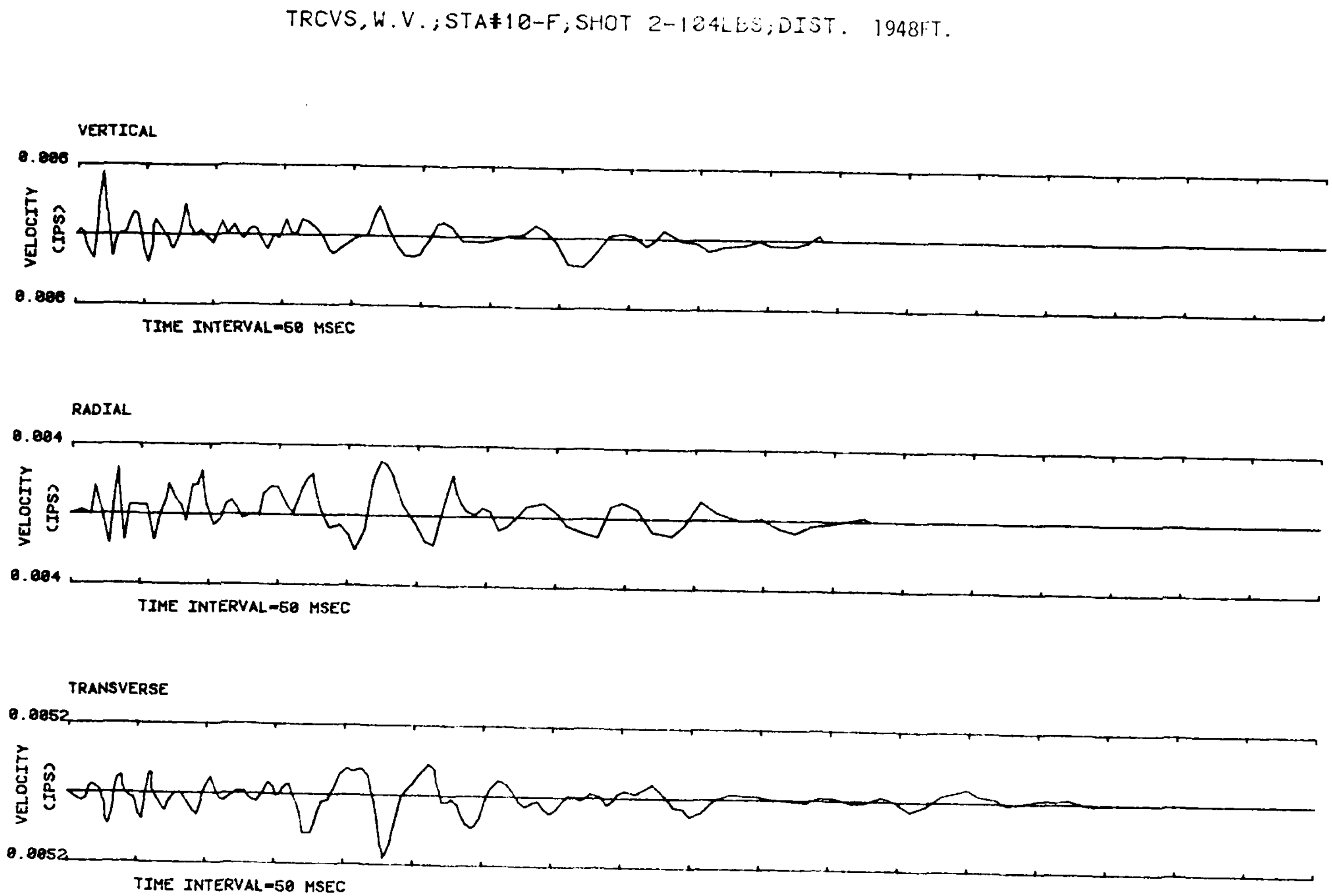

Figure B.13 Vertical, radial and transverse particle velocity measurements, gage canister on concrete slab (rock) at 1948 ft slant distance.

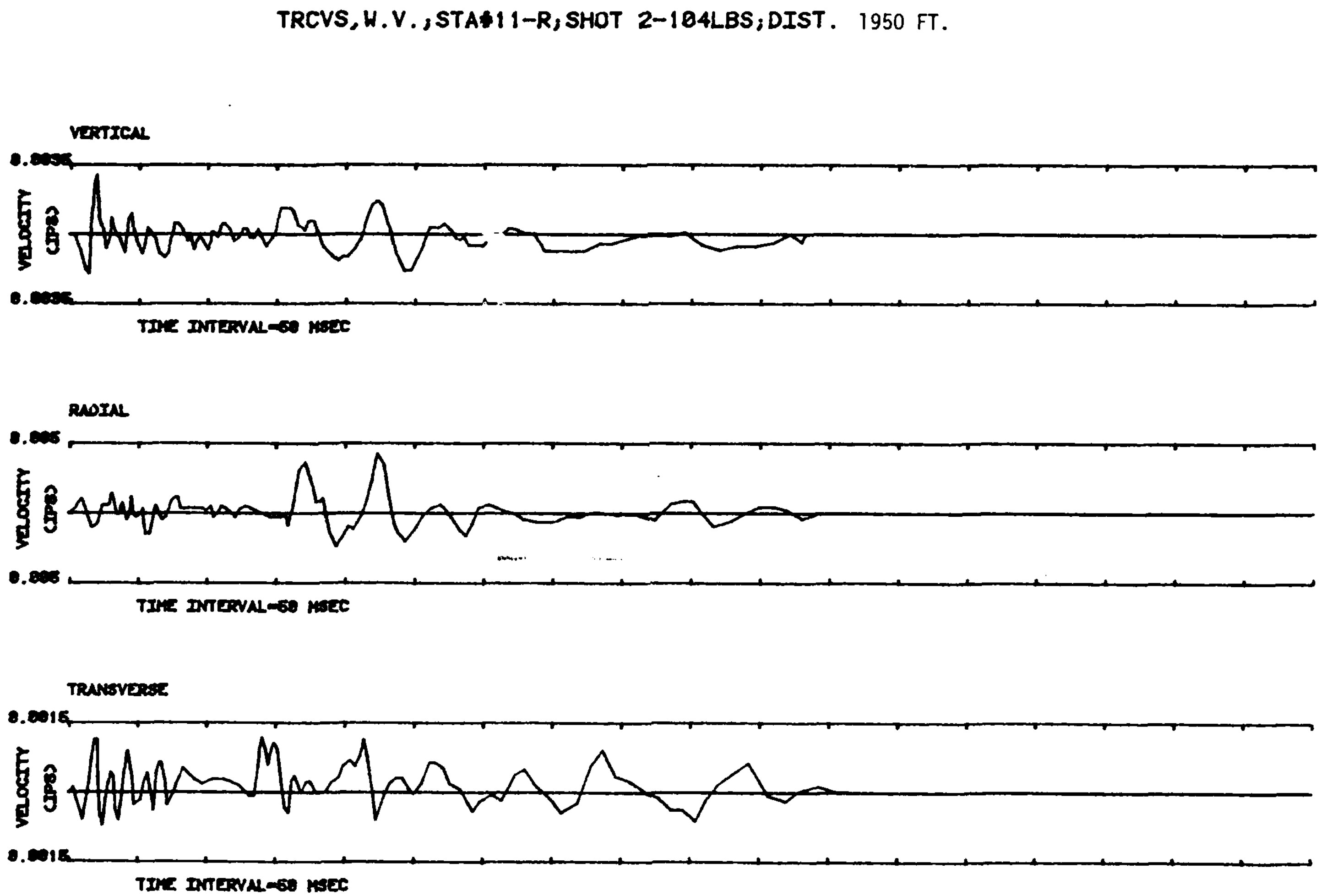

Figure B.14 Vertical, radial and transverse particle velocity measurements, gage canister on rock at 1950 ft slant distance.

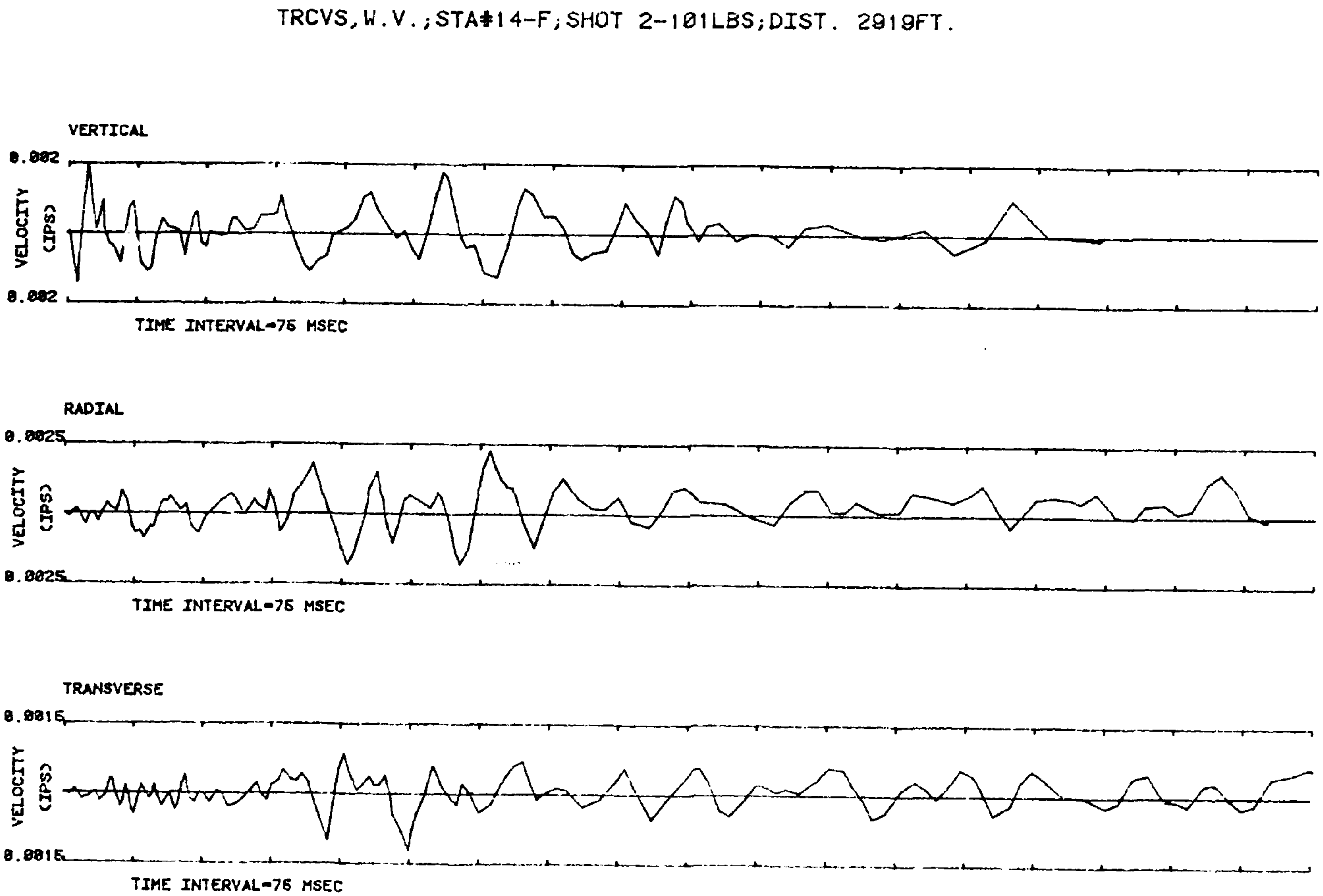

Figure B.15 Vertical, radial and transverse particle velocity measurements, gage canister on swimming pool deck (soil) at 2919 ft slant distance.

TRCVS,W.V.;STA#15-S;SHOT 2-101LBS;DIST. 2960FT.

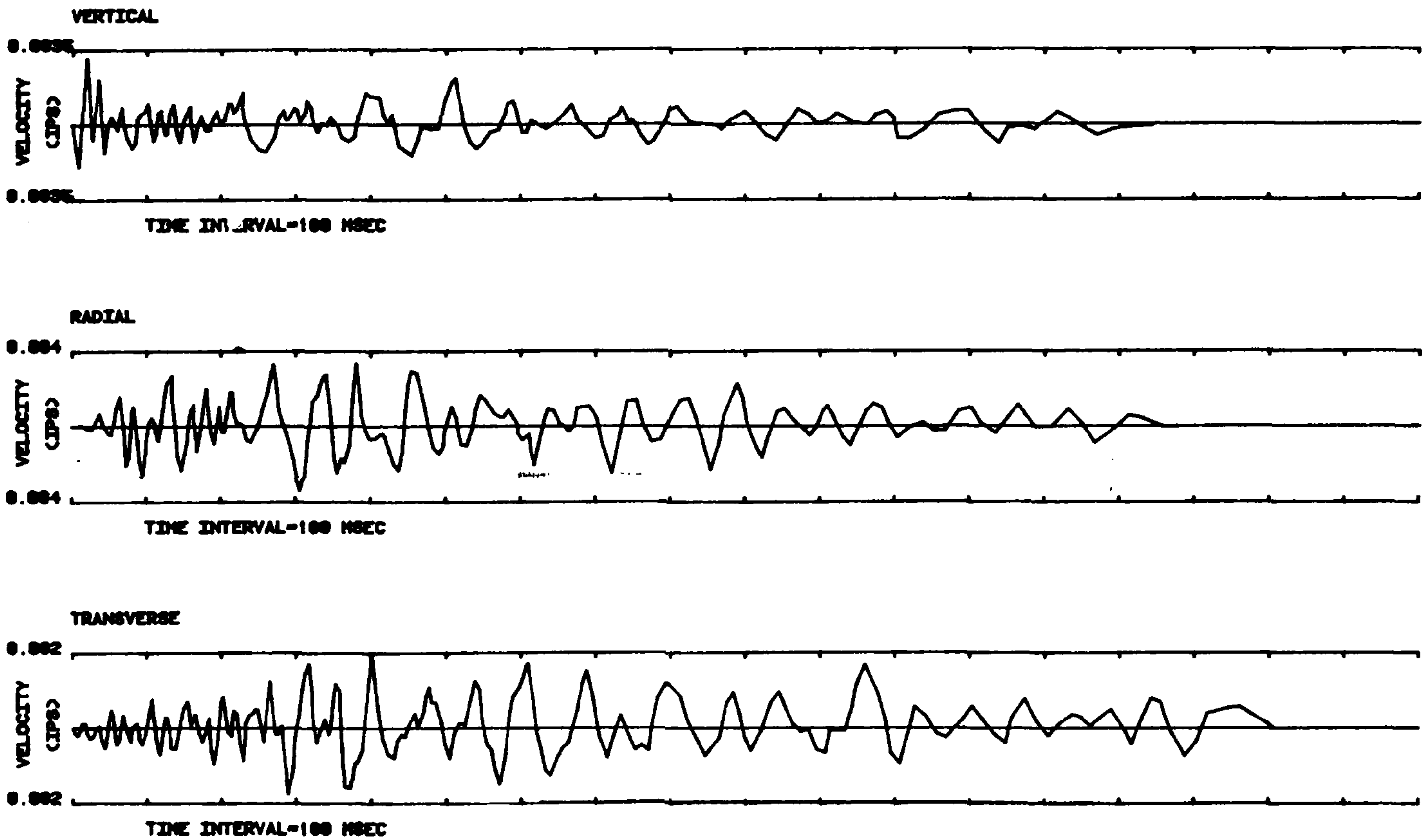

Figure B.16 Vertical, radial and transverse particle velocity measurements, gage canister in soil at 2960 ft slant distance.

TRCVS,W.V.;STA#16-R;SHOT 2;104 LBS;DIST. 2642FT.

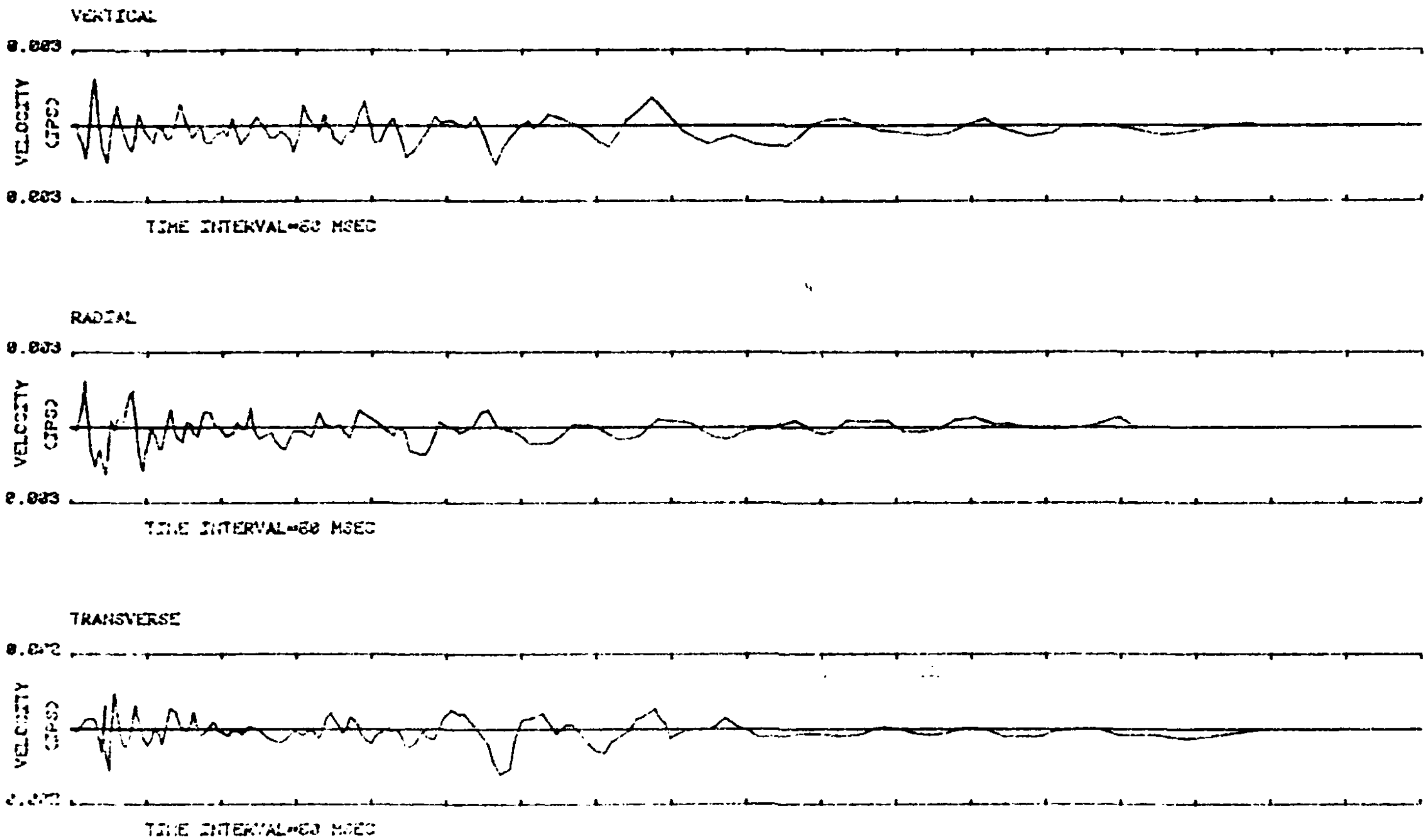

Figure B.17 Vertical, radial and transverse particle velocity measurements, gage canister on weathered rock outcrop outside lined tunnel at 2642 ft slant distance.

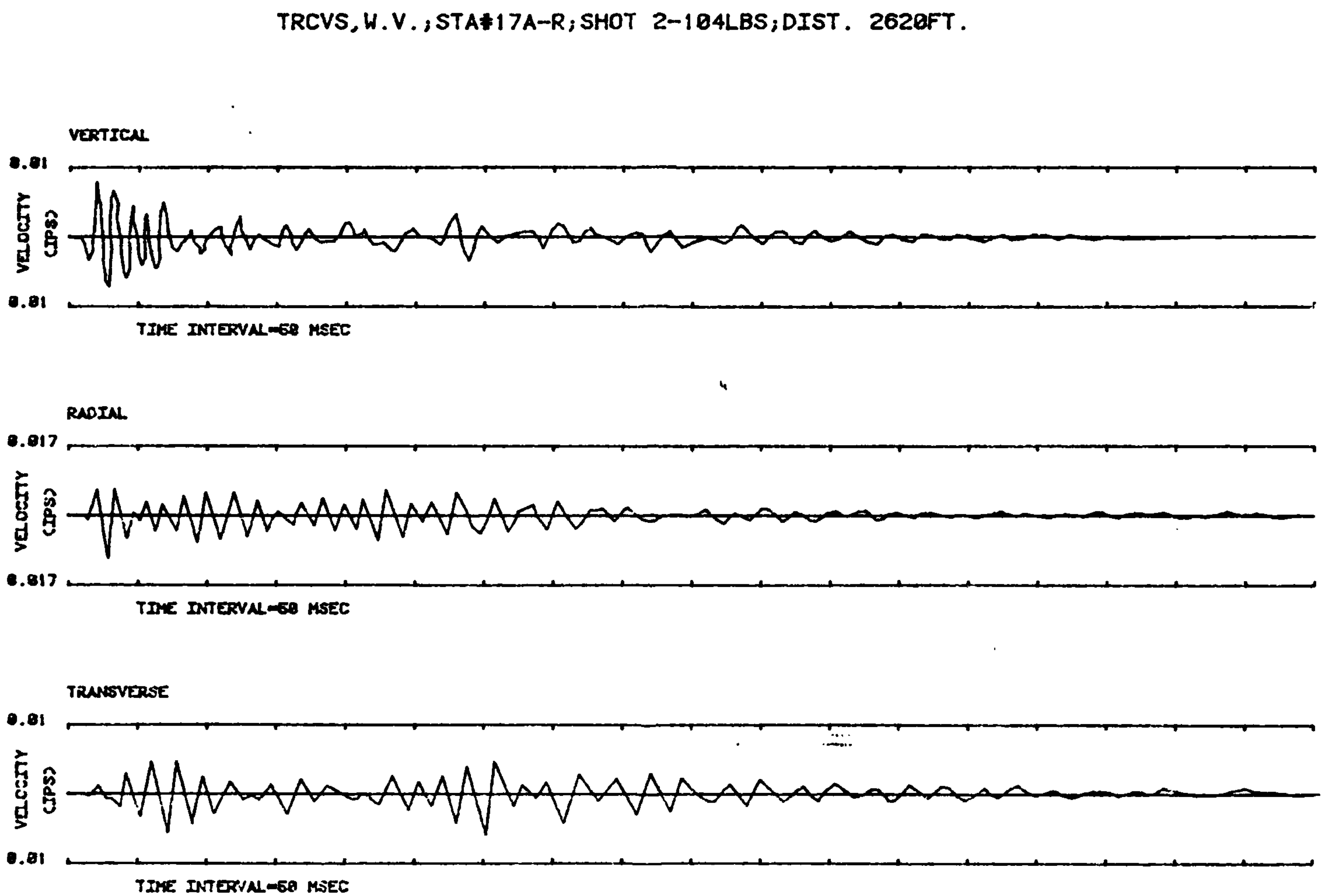

Figure B.18 Vertical, radial and transverse particle velocity measurements, gage canister in unlined tunnel (rock) at 2620 ft slant distance.

APPENDIX C

Shot No. 3

TOTAL CHARGE WEIGHT 104 lb

Prilled Ammonium Nitrate

VELOCITY- AND DISPLACEMENT-TIME HISTORIES

In the ground motion histories in this Appendix (Figures C.1 through C.18), upward trace deflections indicate upward motions for vertical gages and outward motions for horizontal or radial gages.

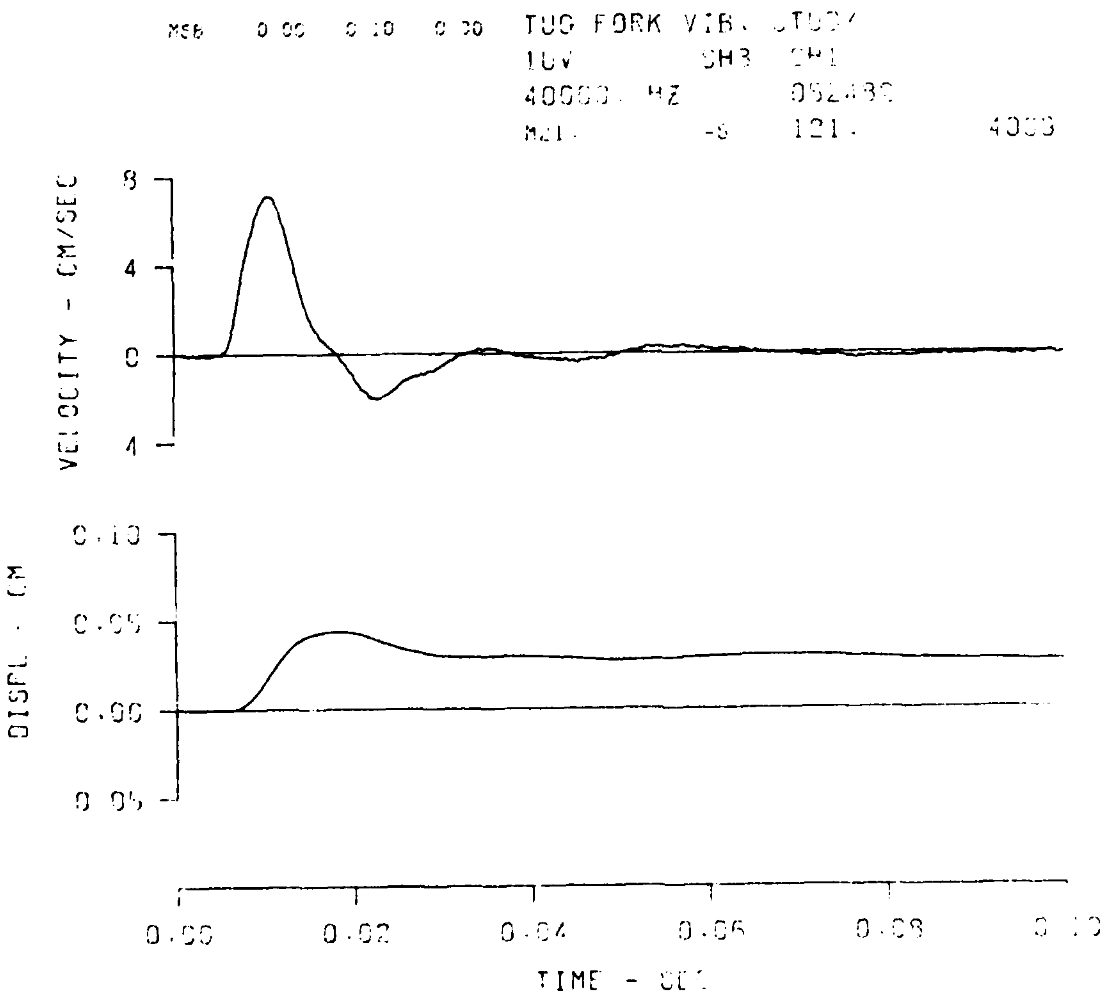

Figure C.1 Vertical particle velocity measurement and integration, gage canister on rock at 38.8 ft slant distance.

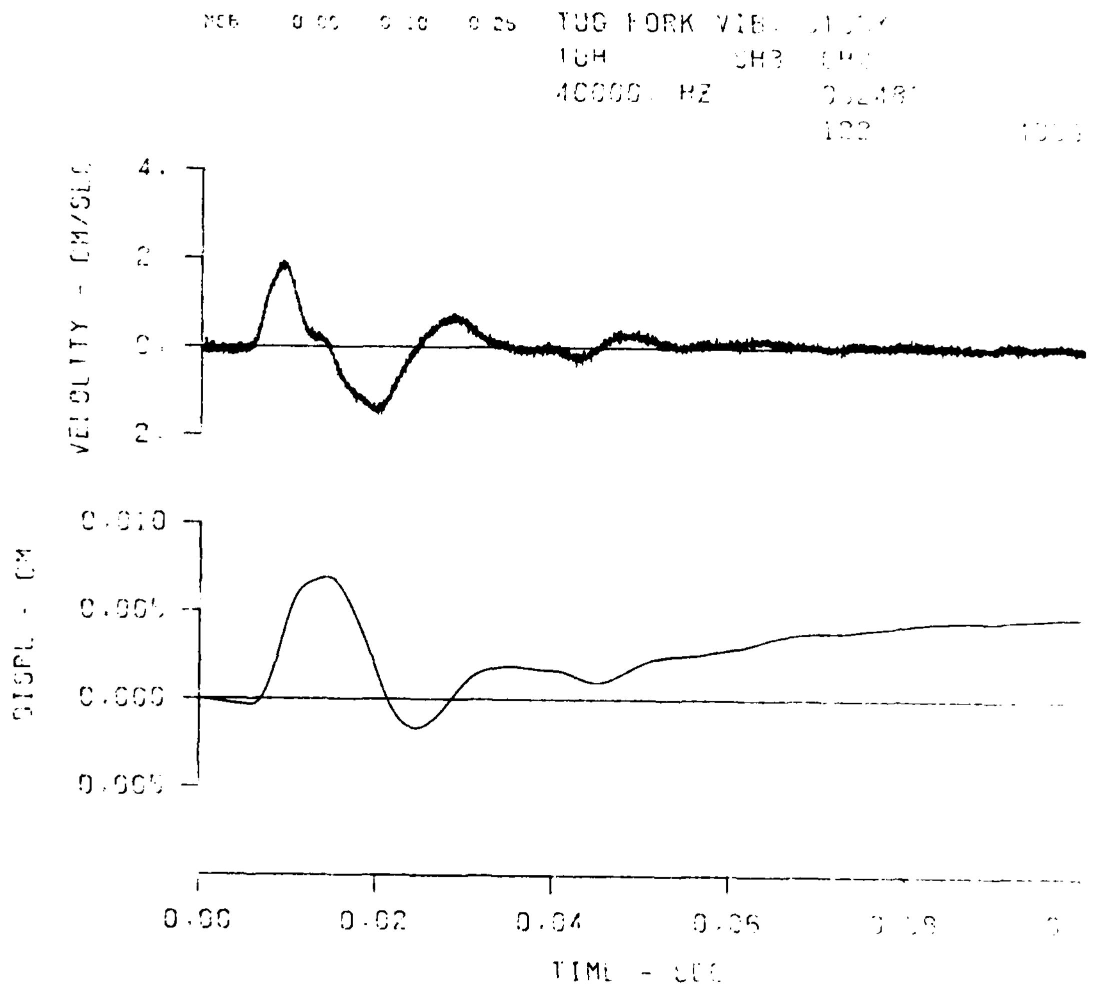

Figure C.2 Horizontal particle velocity measurement and integration. gage canister on rock at 38.8 ft slant distance.

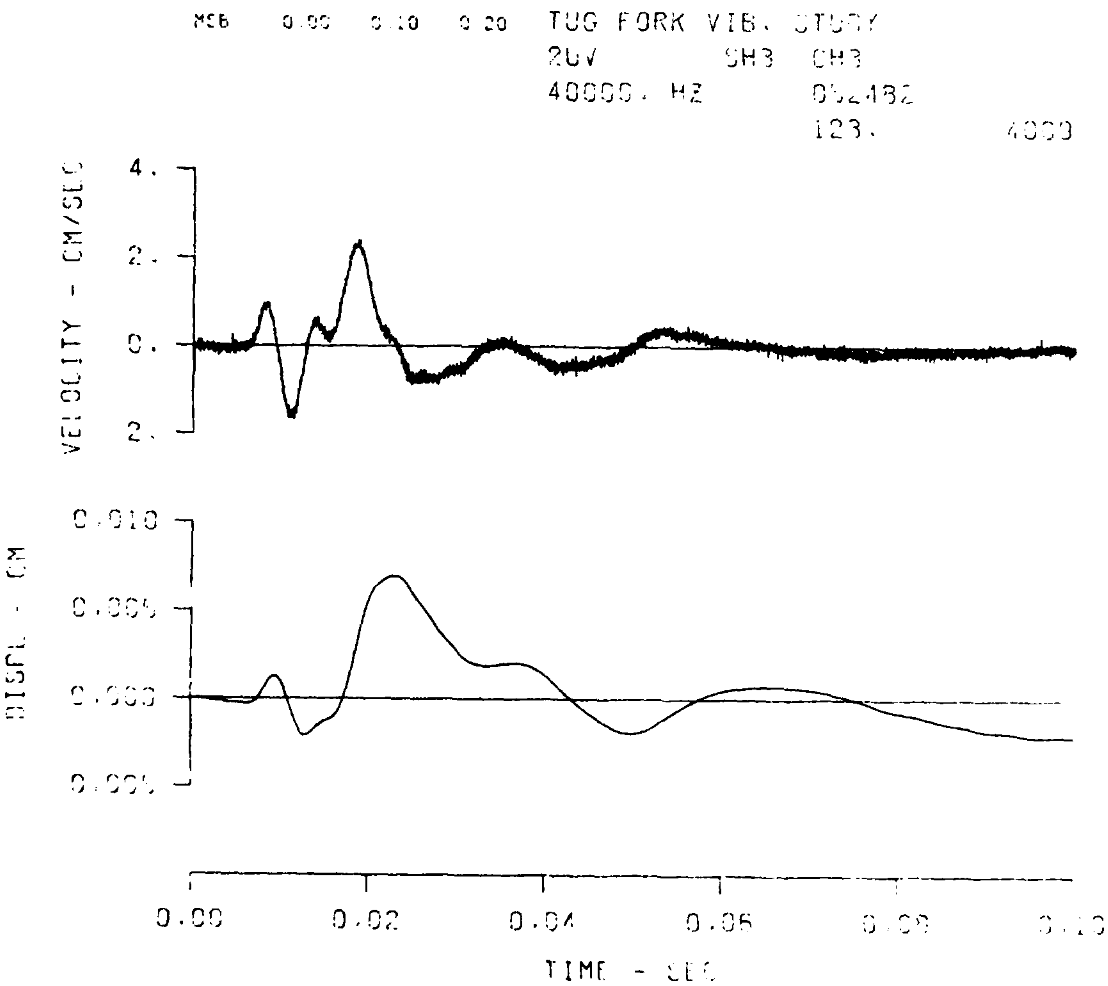

Figure C.3 Vertical particle velocity measurement and integration, gage canister on rock at 48.1 ft slant distance.

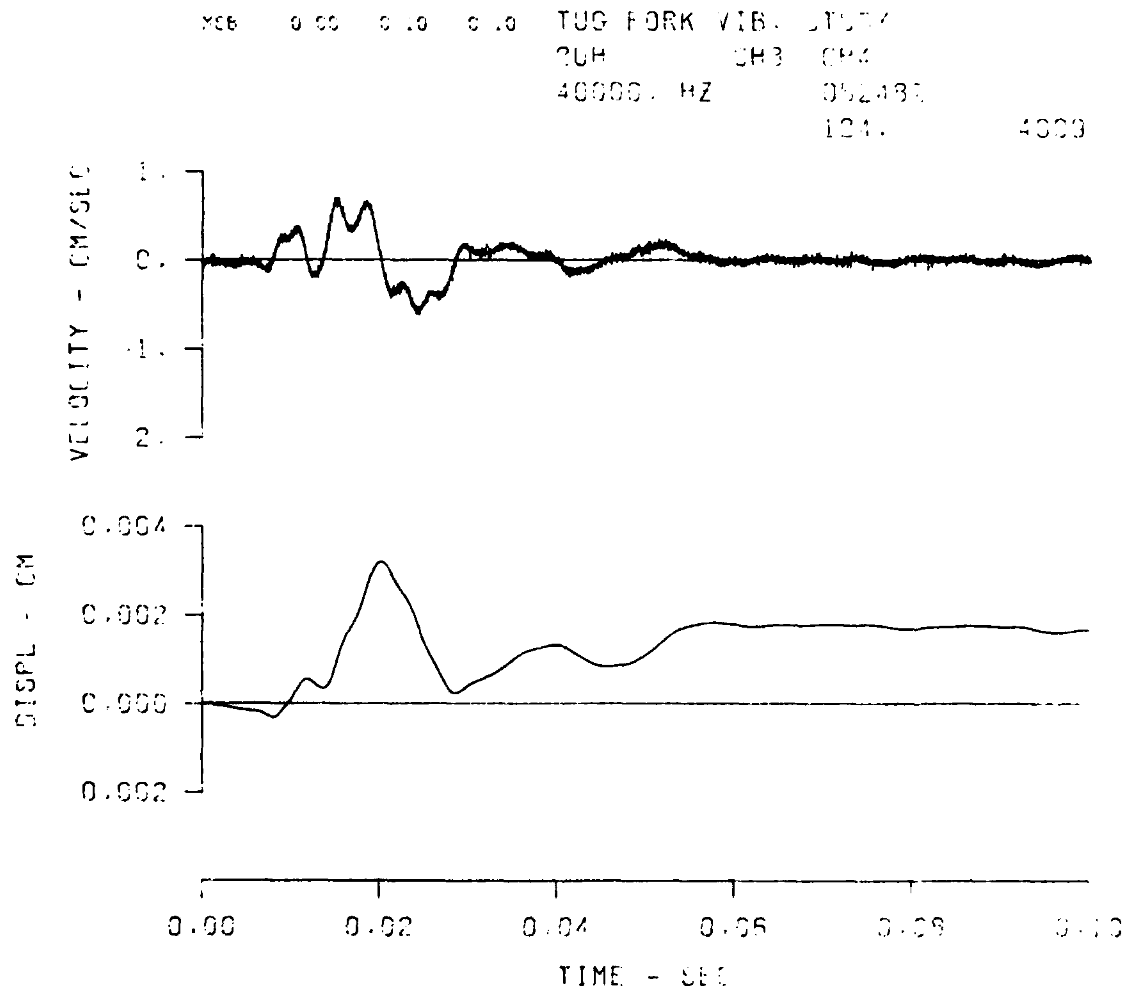

Figure C.4 Horizontal particle velocity measurement and integration, gage canister on rock at 48.1 ft slant distance.

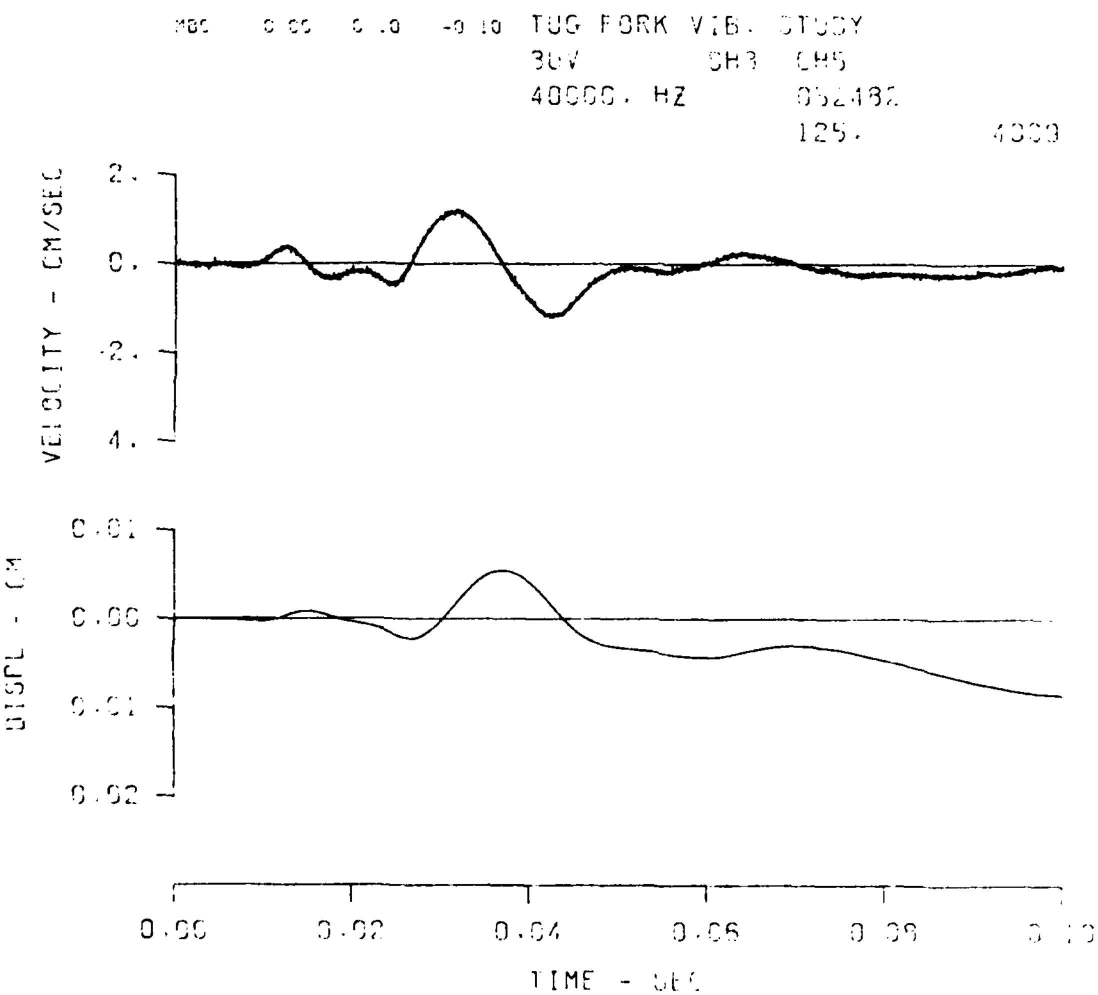

Figure C.5 Vertical particle velocity measurement and integration, gage canister on rock at 64.5 ft slant distance.

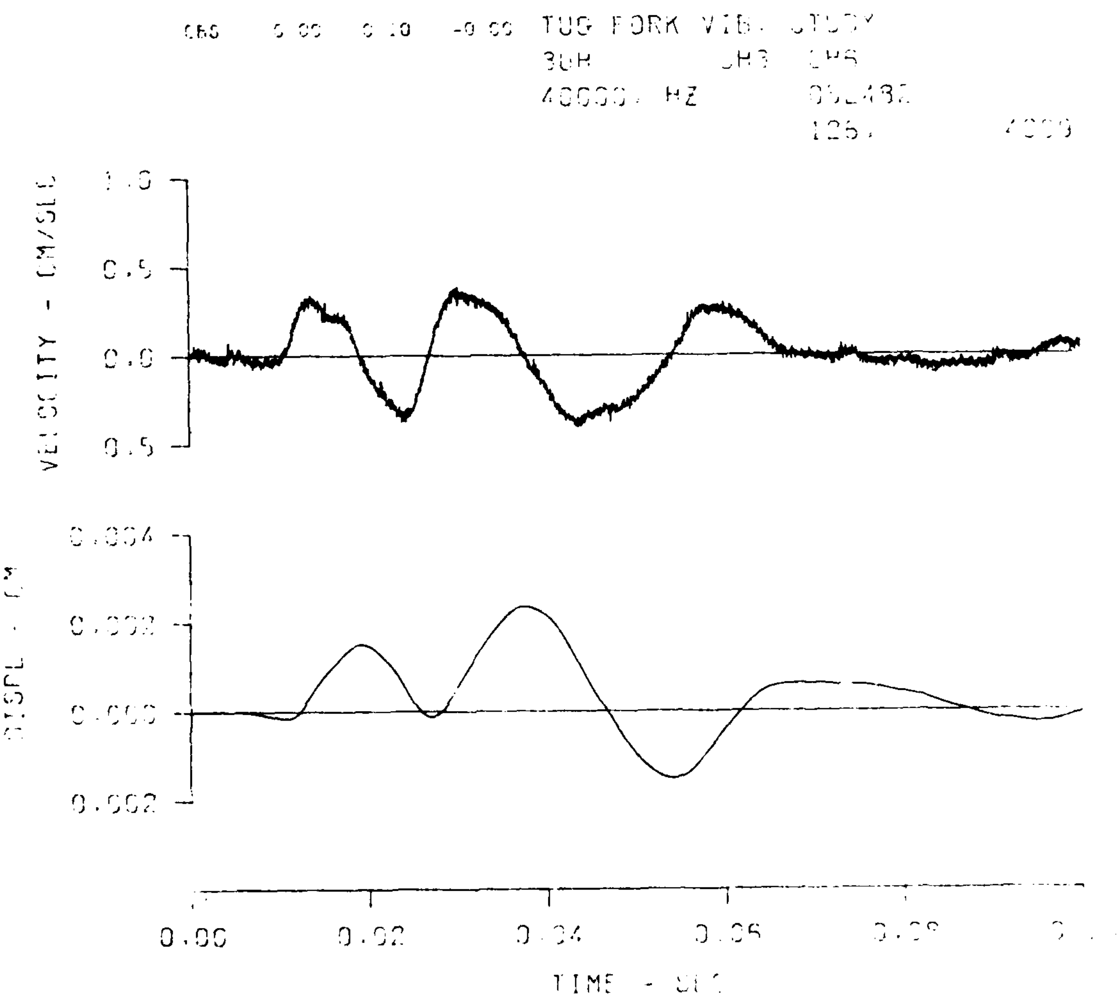

Figure C.6 Horizontal particle velocity measurement and integration, gage canister on rock at 64.5 ft slant distance.

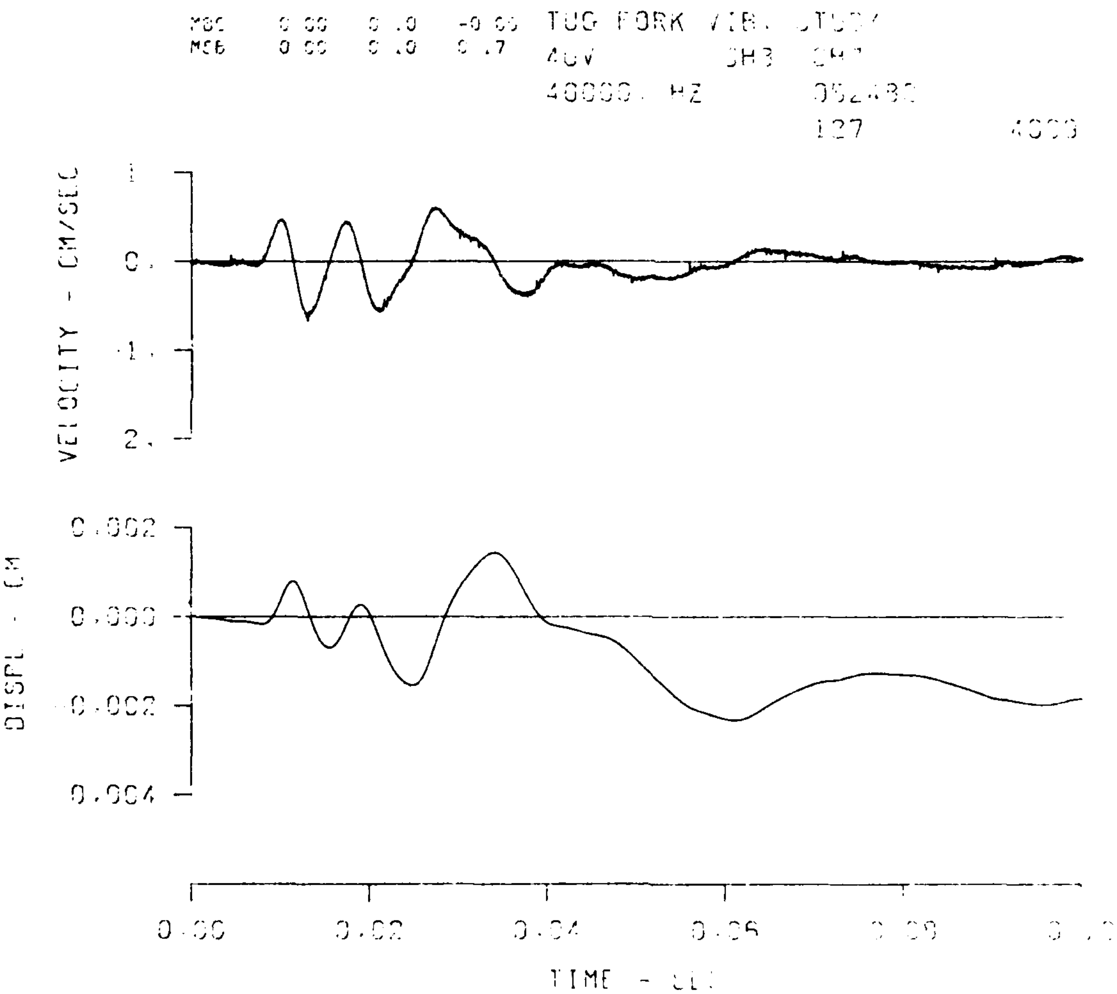

Figure C.7 Vertical particle velocity measurement and integration, gage canister on rock at 76.8 ft stant distance.

AD-A130 271 TUG FORK RIVER BIG BEND CUTOFF BLAST MONITORING STUDY (U) ARMY ENGINEER WATERWAYS EXPERIMENT STATION VICKSBURG MS STRUCTURES LAB C E JOACHIM MAR 83 2/2

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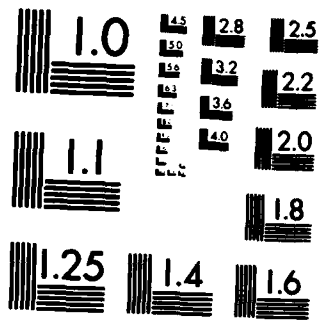

MICROCOPY RESOLUTION TEST CHART
NATIONAL BUREAU OF STANDARDS-1963-A

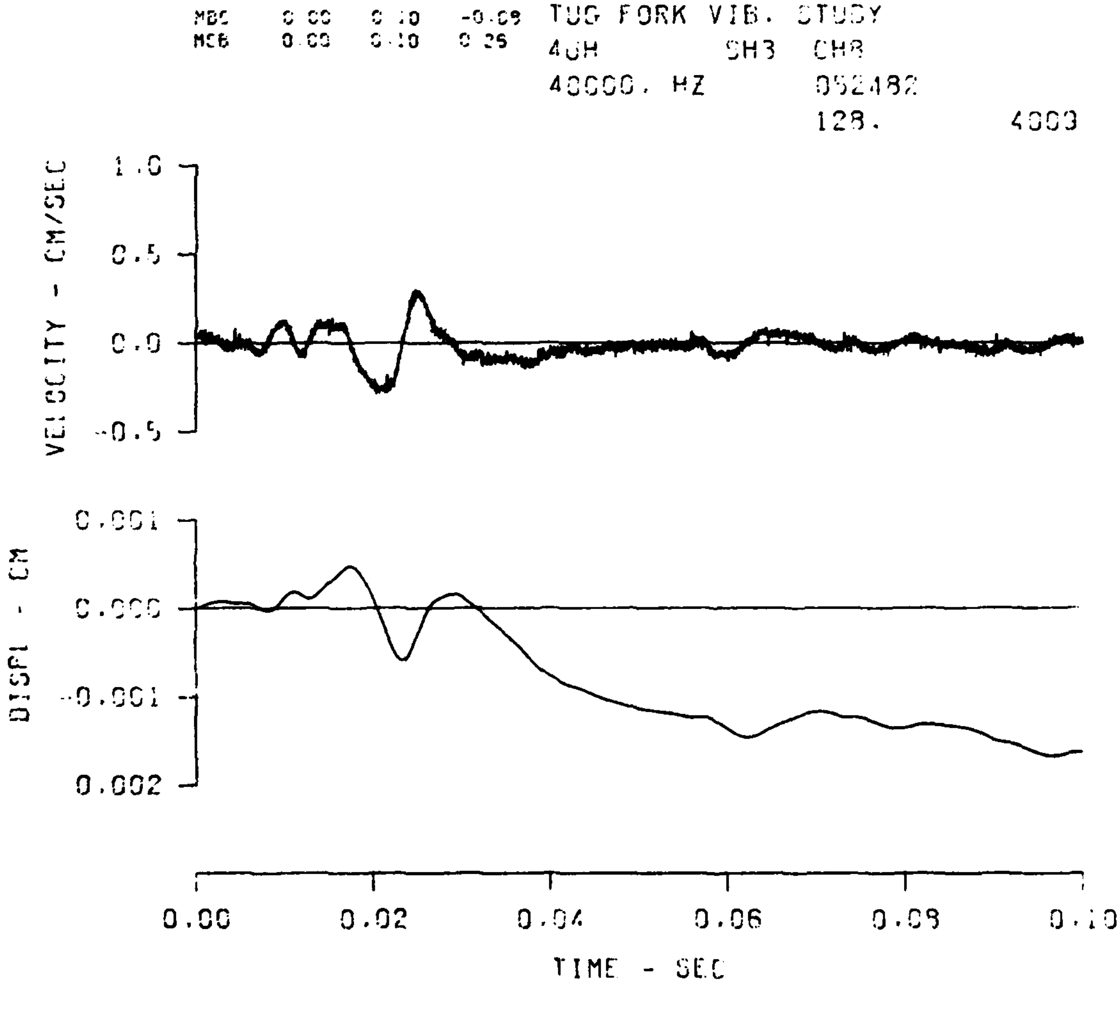

Figure C.8 Horizontal particle velocity measurement and integration, gage canister on rock at 76.8 ft slant distance.

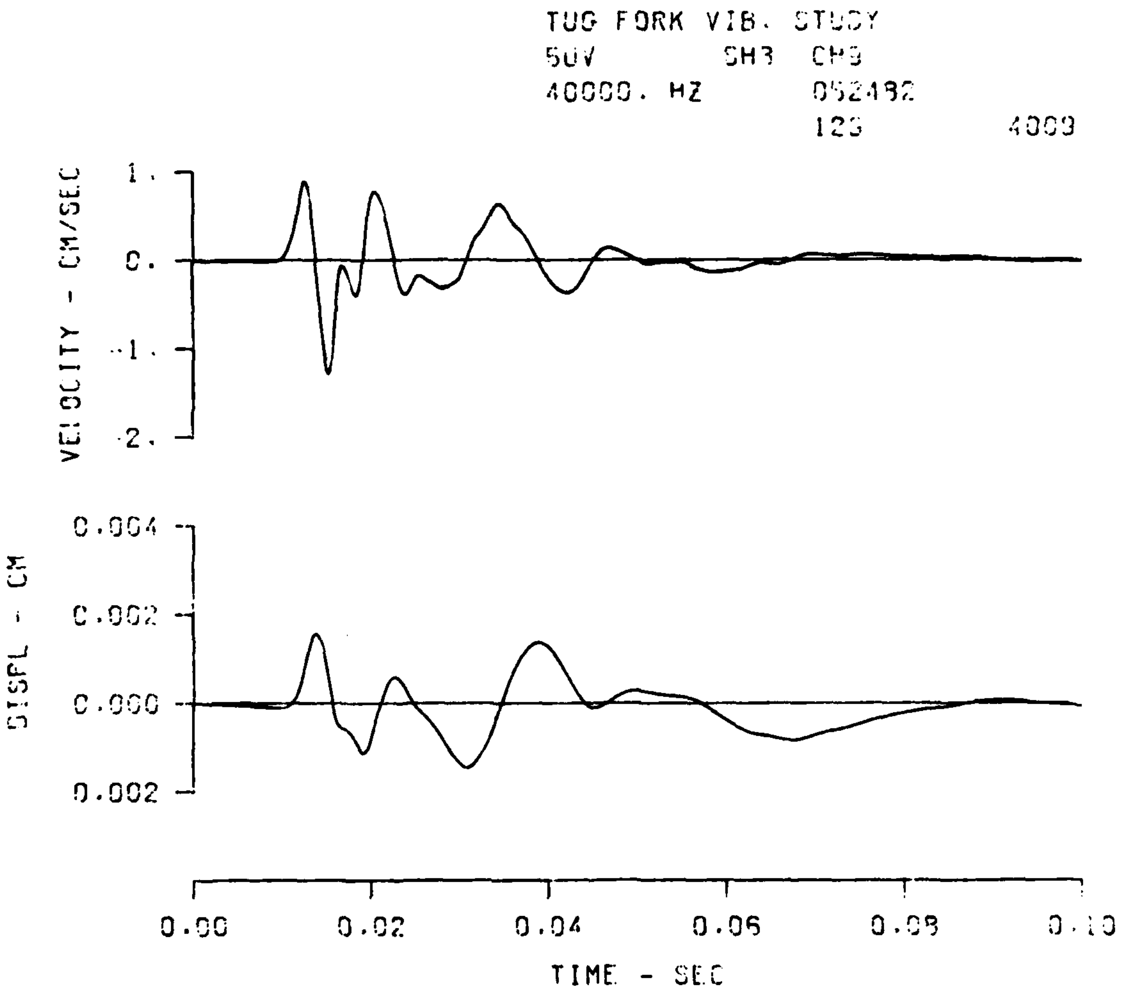

Figure C.9 Vertical particle velocity measurement and integration, gage canister on rock at 108 ft slant distance.

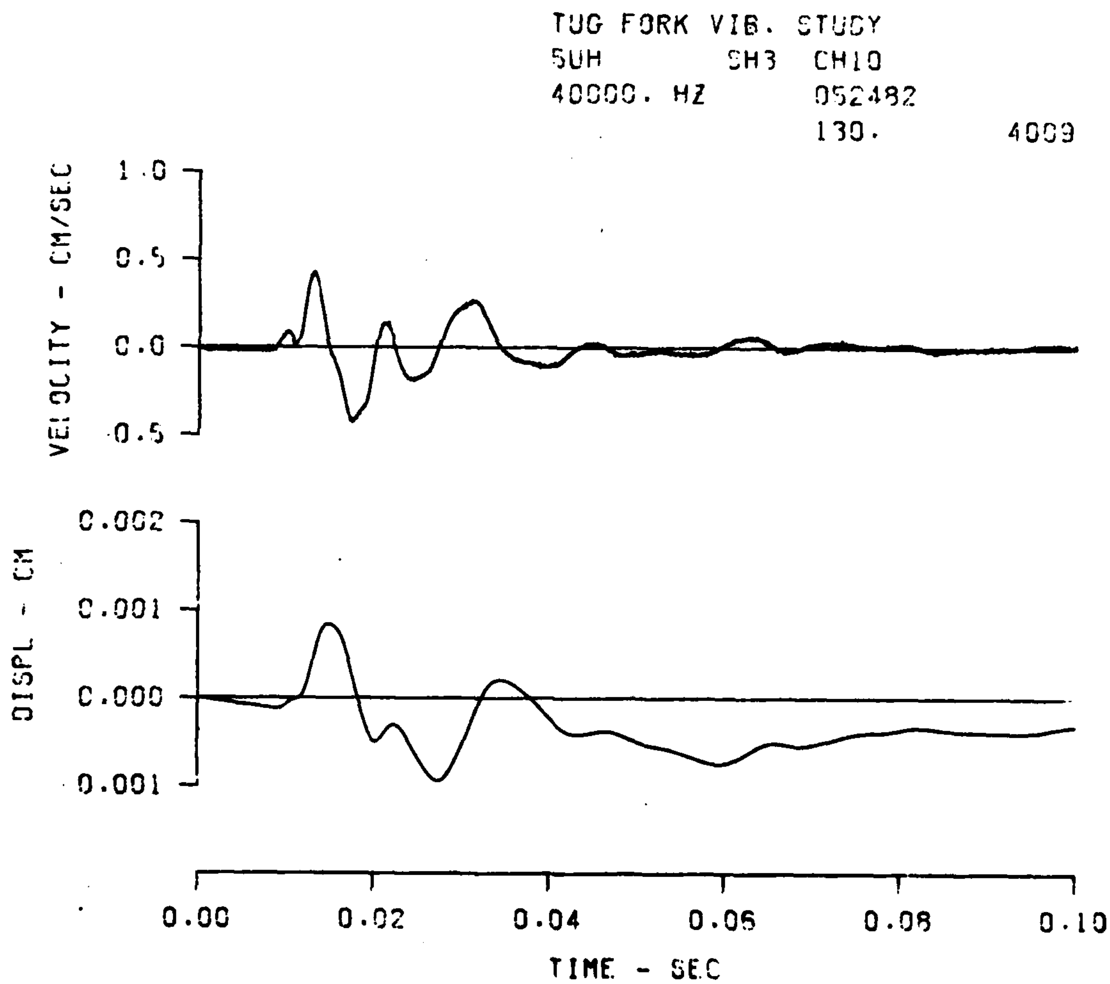

Figure C.10 Horizontal particle velocity measurement and integration, gage canister on rock at 108 ft slant distance.

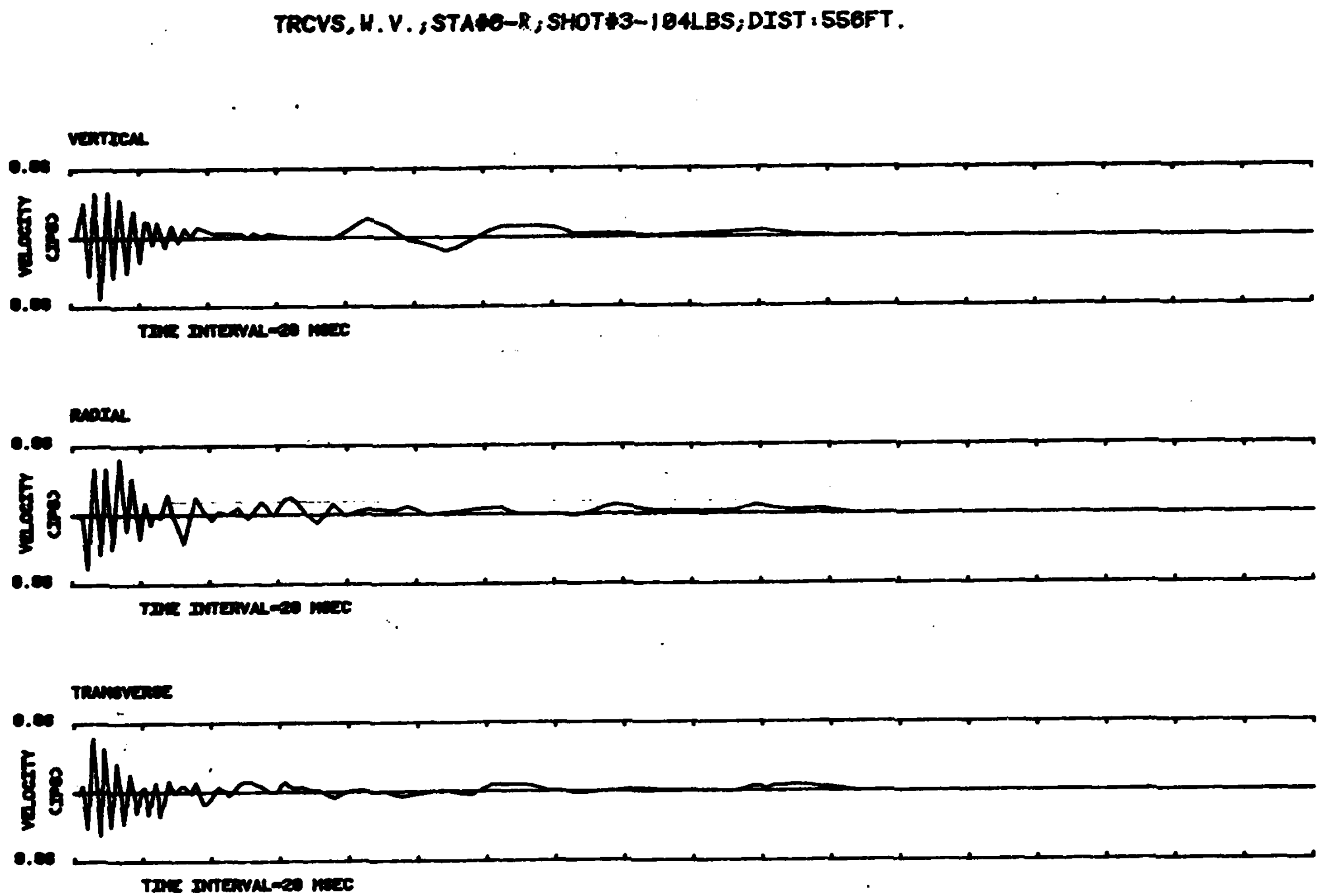

Figure C.11 Vertical, radial and transverse particle velocity measurements, gage canister on rock at 556 ft slant distance.

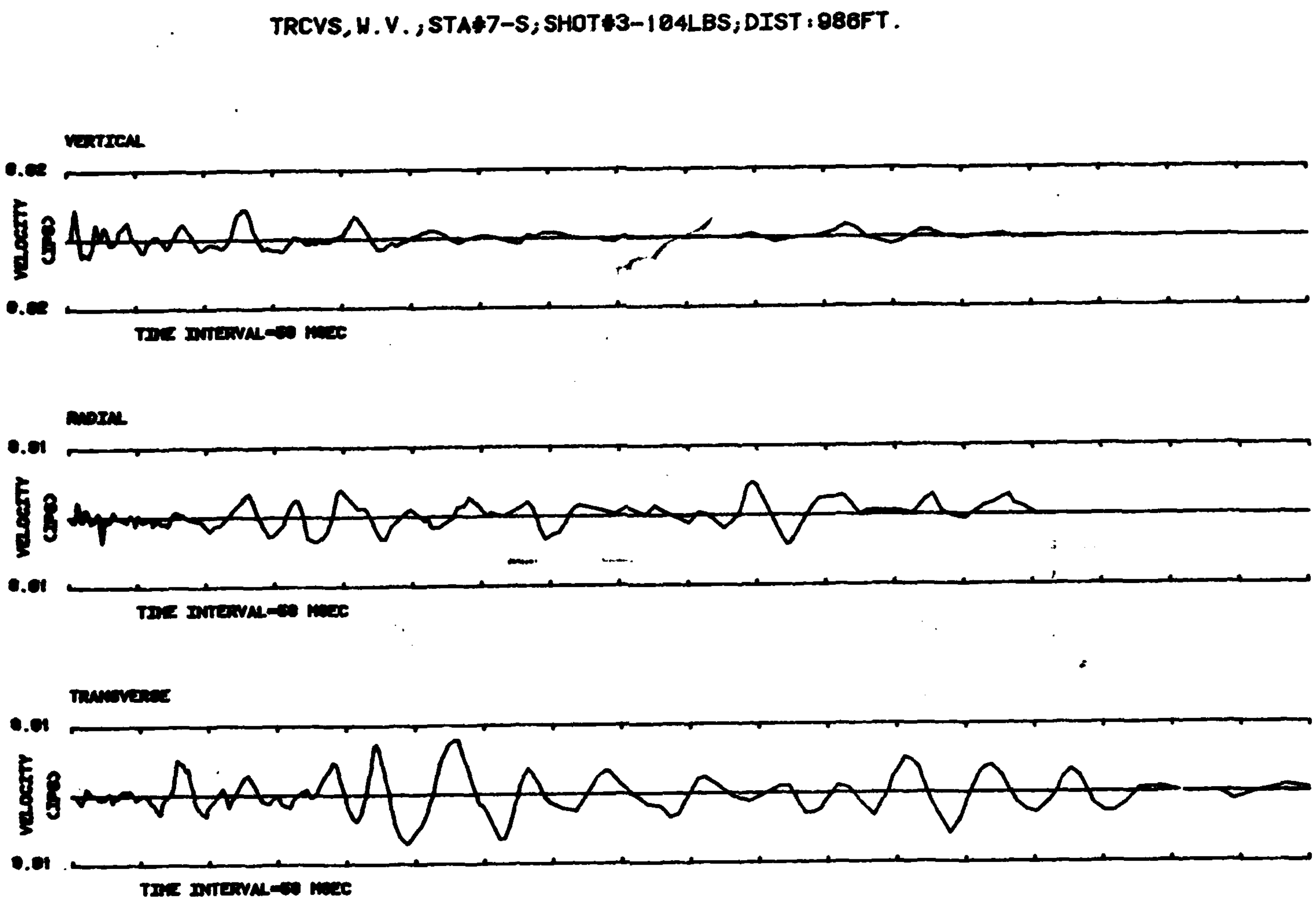

Figure C.12 Vertical, radial and transverse particle velocity measurements, gage canister in soil at 986 ft slant distance.

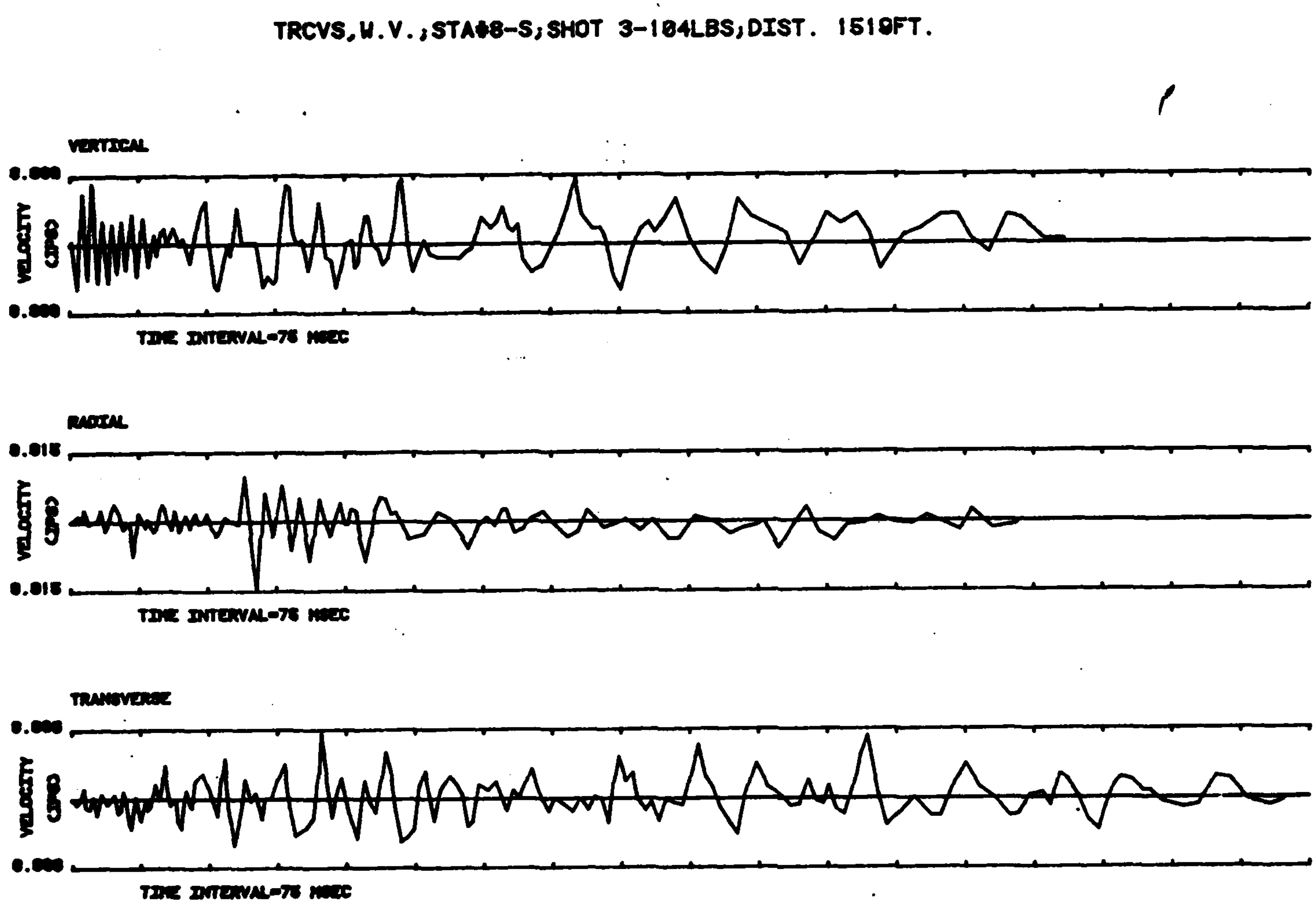

Figure C.13 Vertical, radial and transverse particle velocity measurements, gage canister in soil at 1519 ft slant distance.

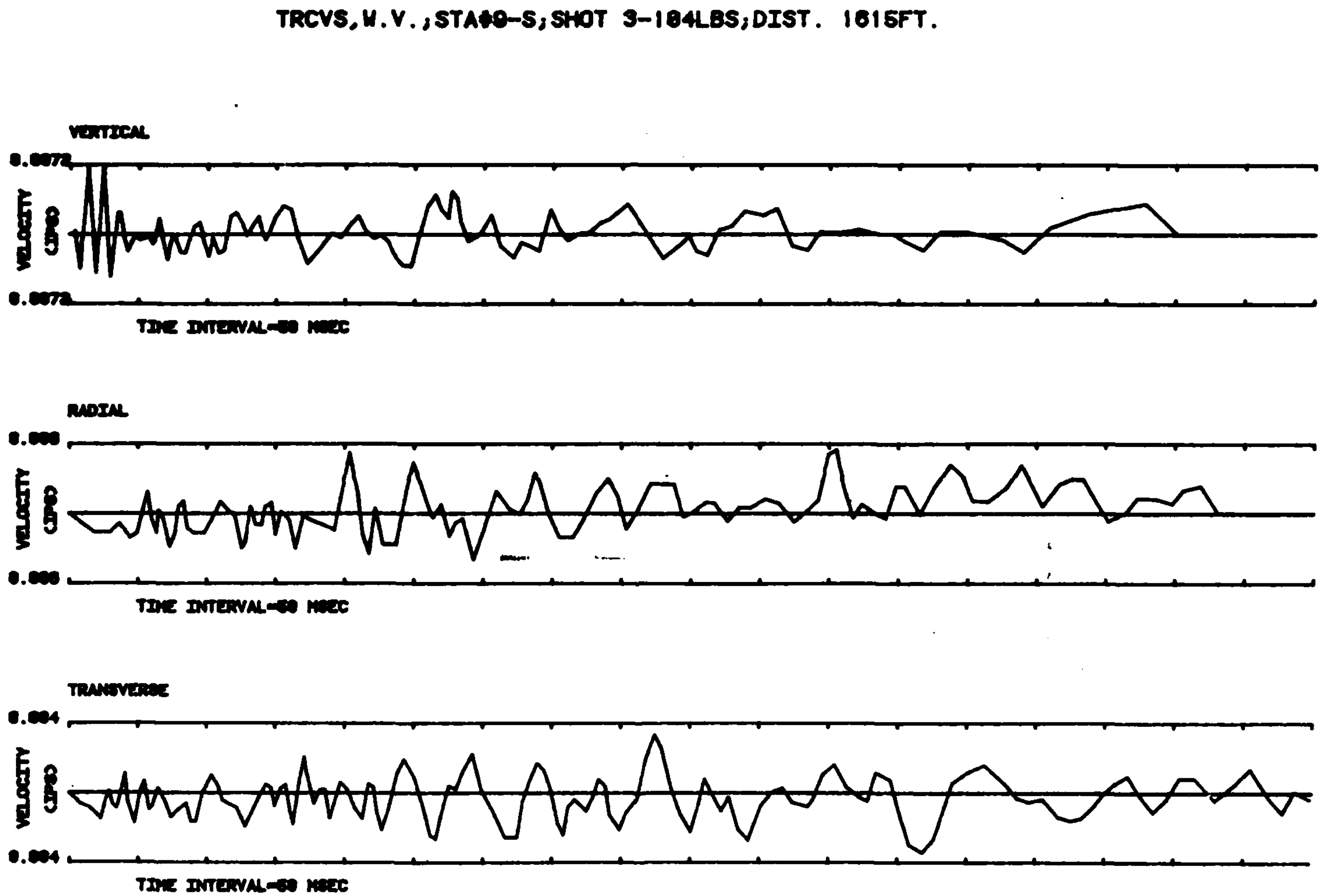

Figure C.14 Vertical, radial and transverse particle velocity measurements, gage canister in soil at 1615 ft slant distance.

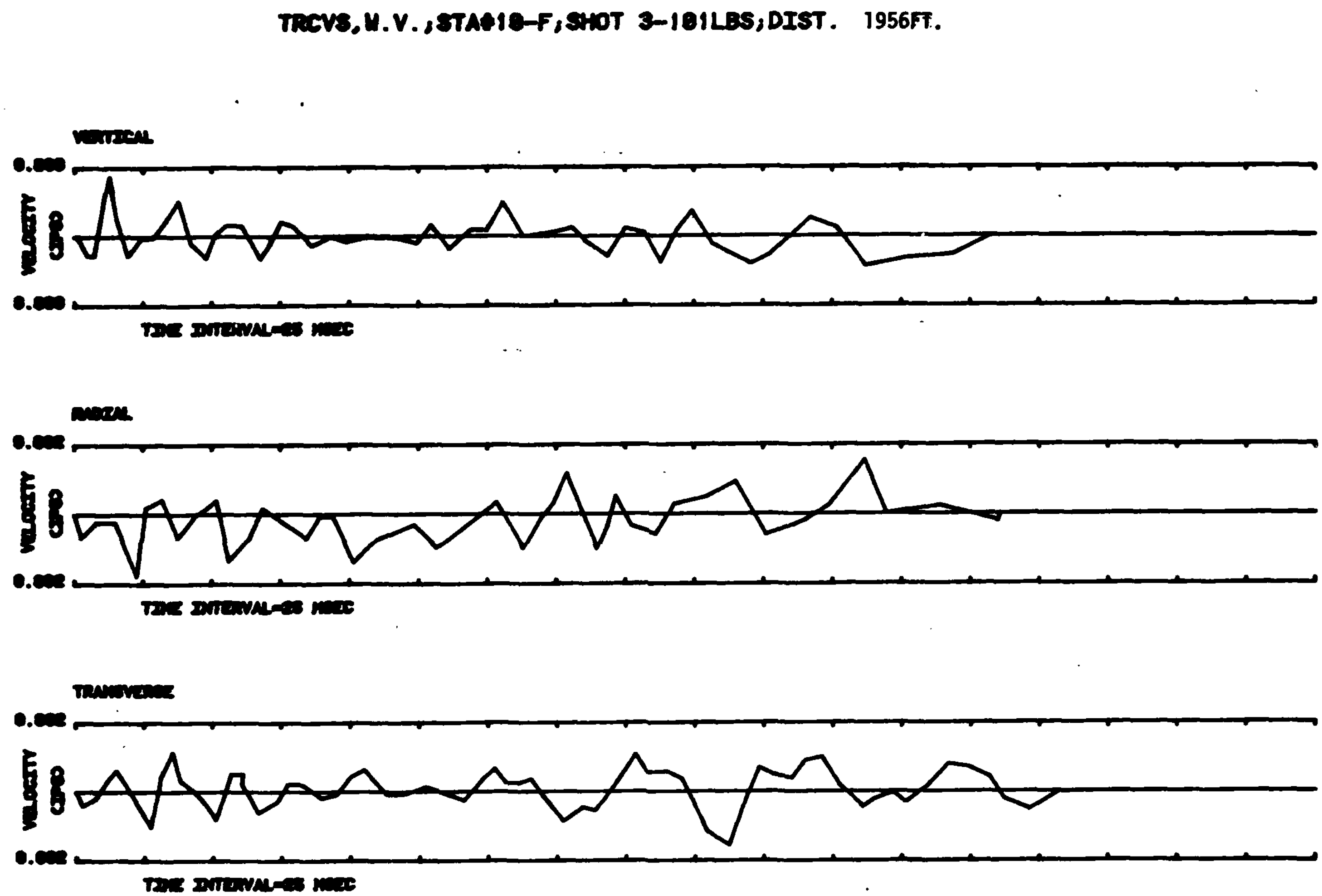

Figure C.15 Vertical, radial and transverse particle velocity measurements, gage canister on concrete slab (rock) at 1956 ft slant distance.

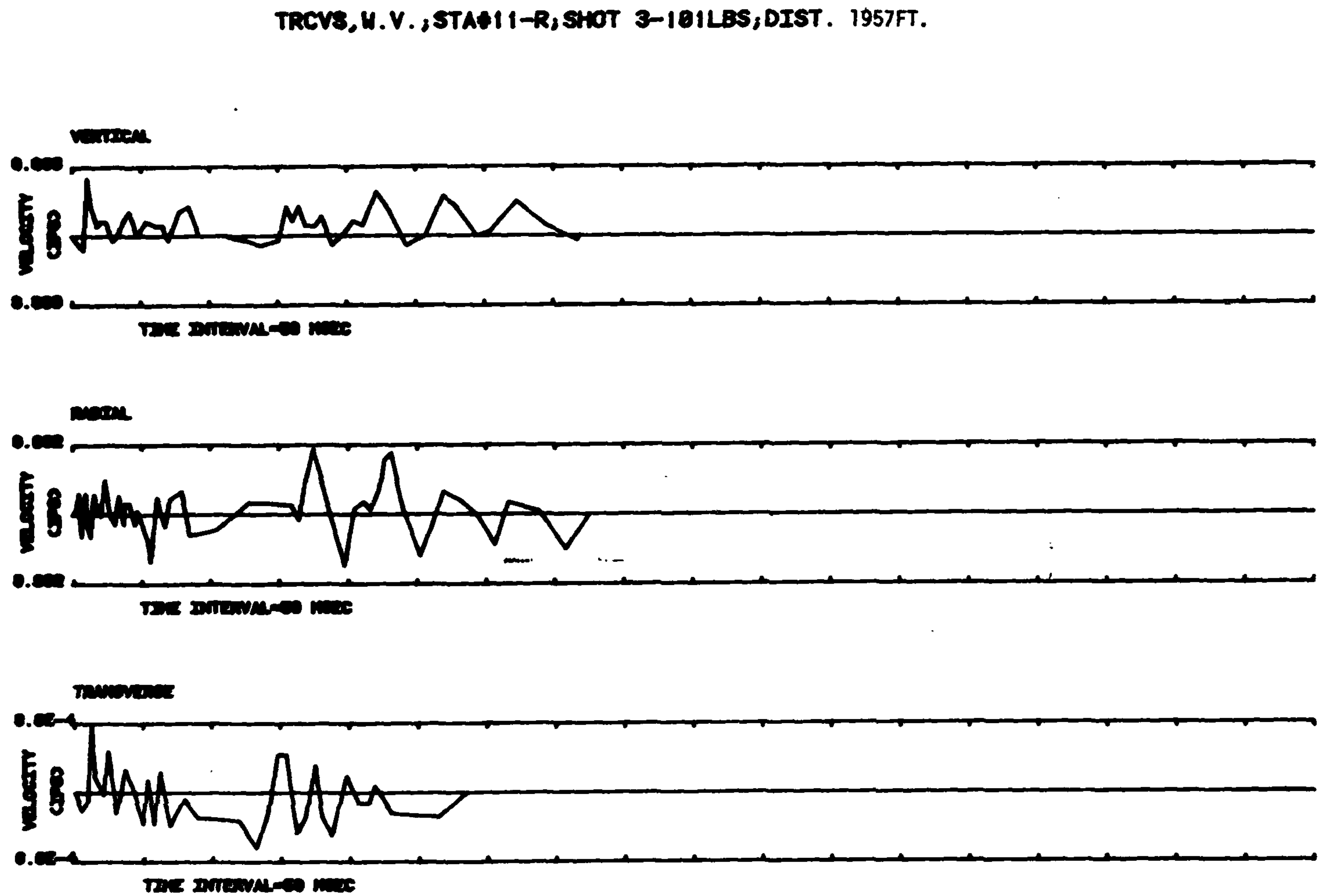

Figure C.16 Vertical, radial and transverse particle velocity measurements, gage canister on rock at 1957 ft slant distance.

TRCVS,W.V.;STA#16-R;SHOT 3;104 LBS;DIST. 2635FT.

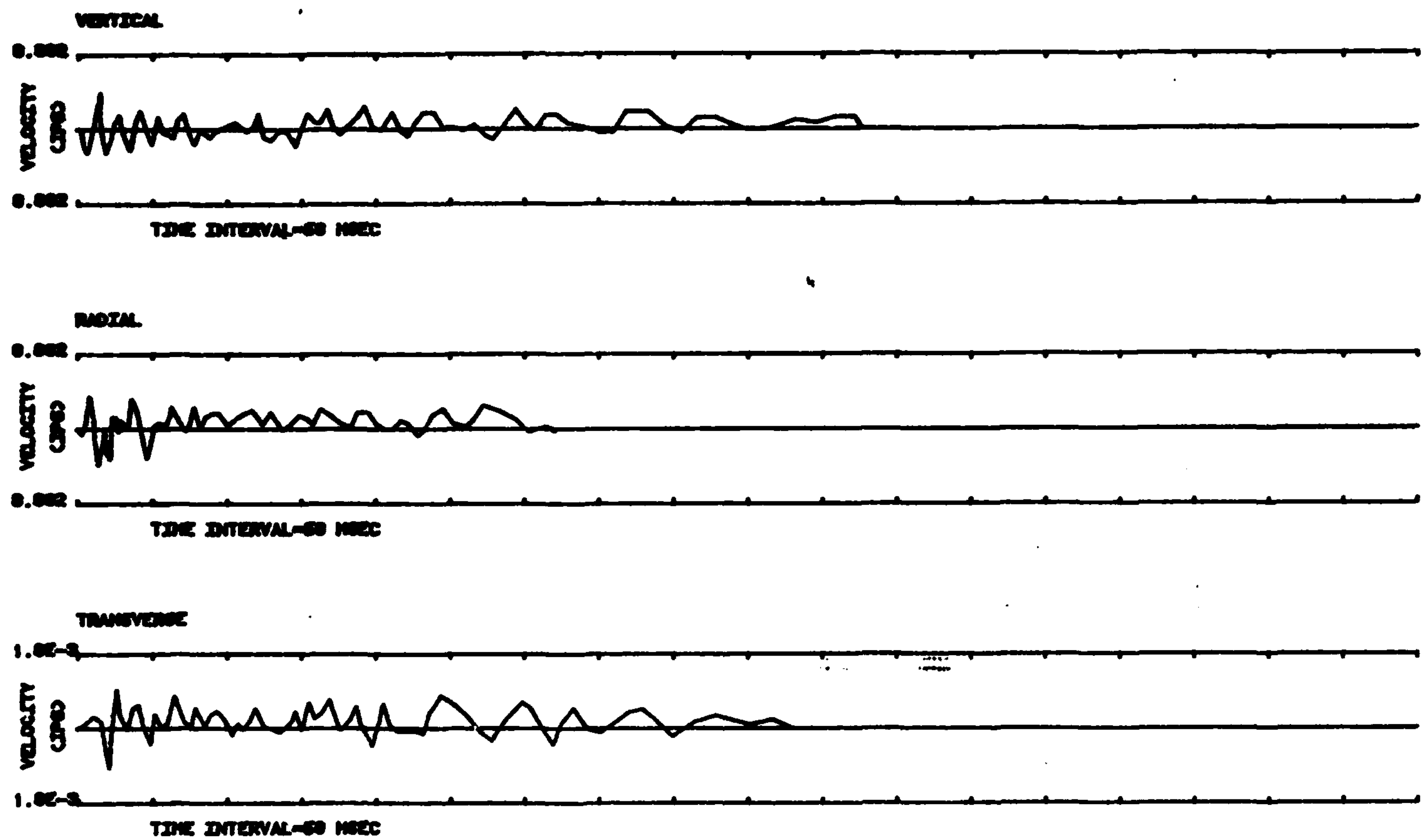

Figure C.17 Vertical, radial and transverse particle velocity measurements, gage canister on tunnel liner (rock) at 2635 ft slant distance.

TRCVS,W.V.;STA#17-R;SHOT 3;104 LBS;DIST. 2708FT.

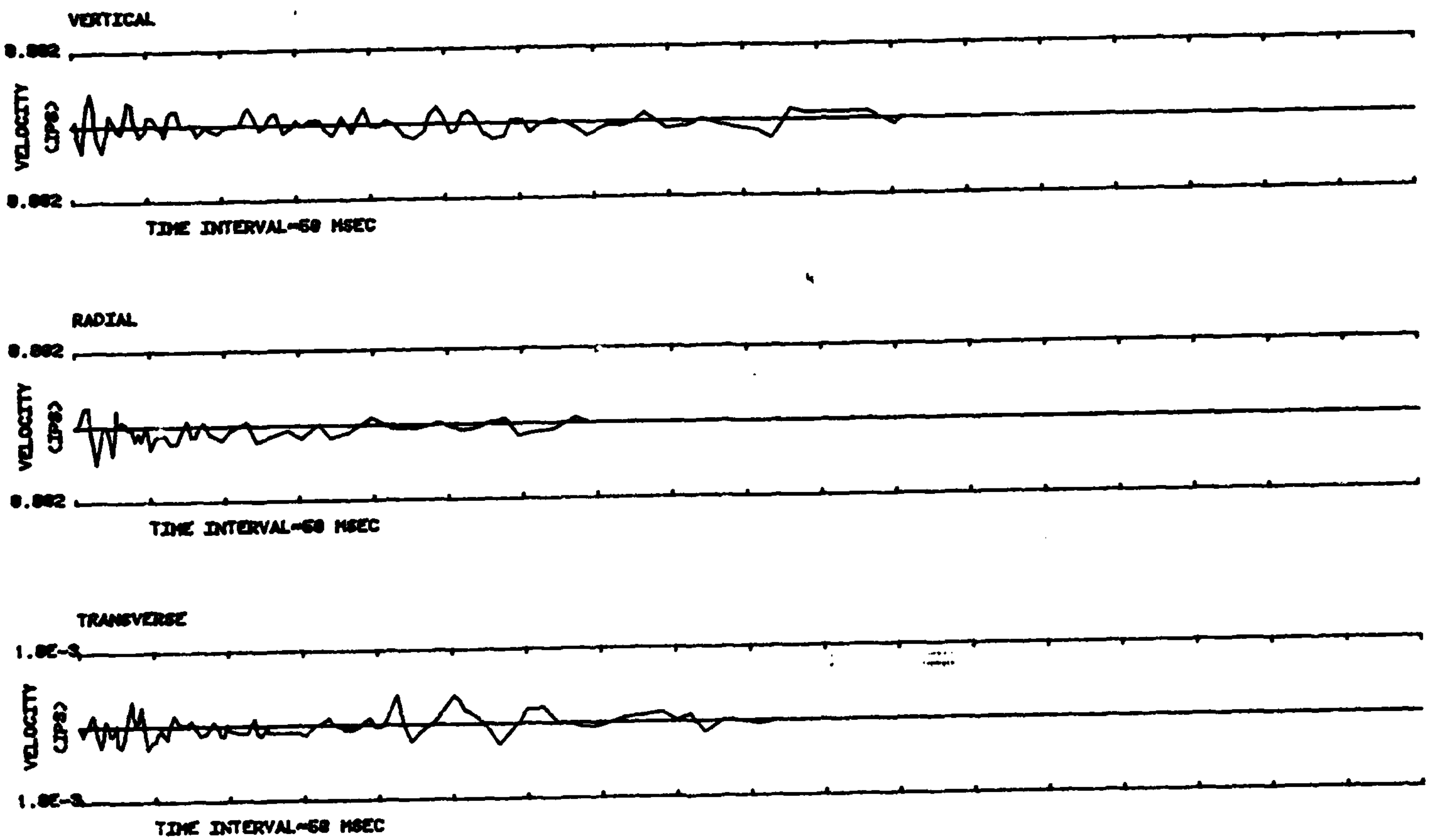

Figure C.18 Vertical, radial and transverse particle velocity measurements, gage canister in unlined tunnel (rock) at 2708 ft slant distance.

APPENDIX D

Shot No. 4

TOTAL CHARGE WEIGHT 311 lbs

Prilled Ammonium Nitrate

VELOCITY- AND DISPLACEMENT-TIME HISTORIES

In the ground motion histories in this Appendix (Figures D.1 through D.18). upward trace deflections indicate upward motions for vertical gages and outward motions for horizontal or radial gages.

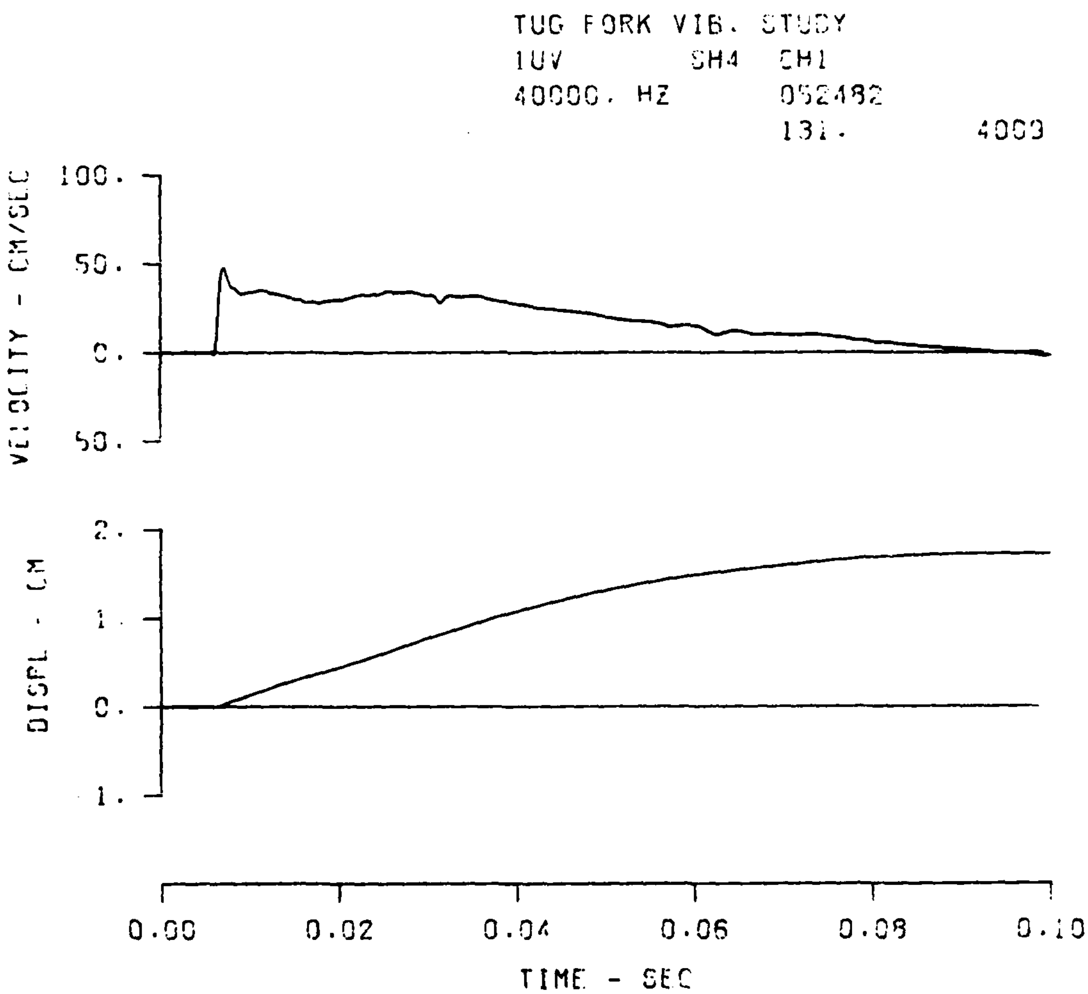

Figure D.1 Vertical particle velocity measurement and integration, gage canister on rock at 50.1 ft slant distance.

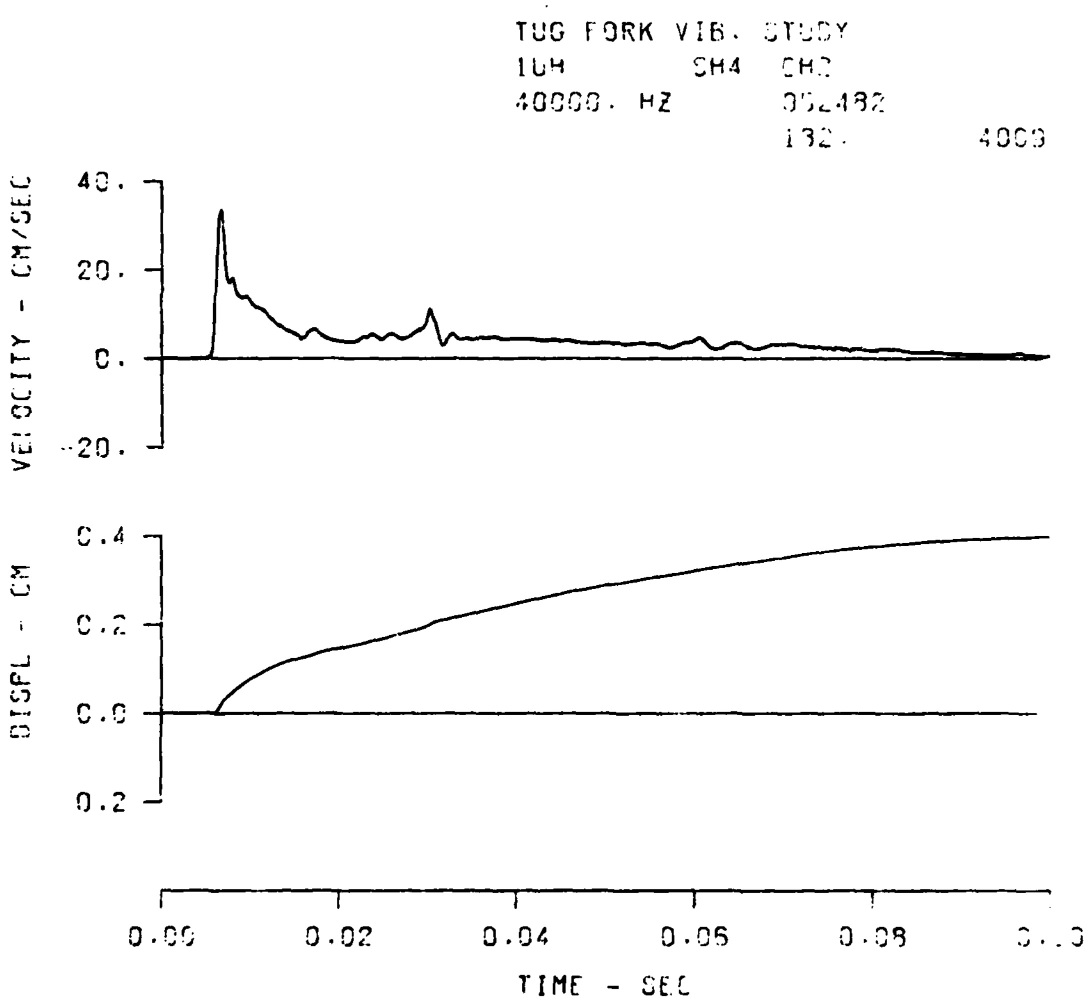

Figure D.2 Horizontal particle velocity measurement and integration, gage canister on rock at 50.1 ft slant distance.

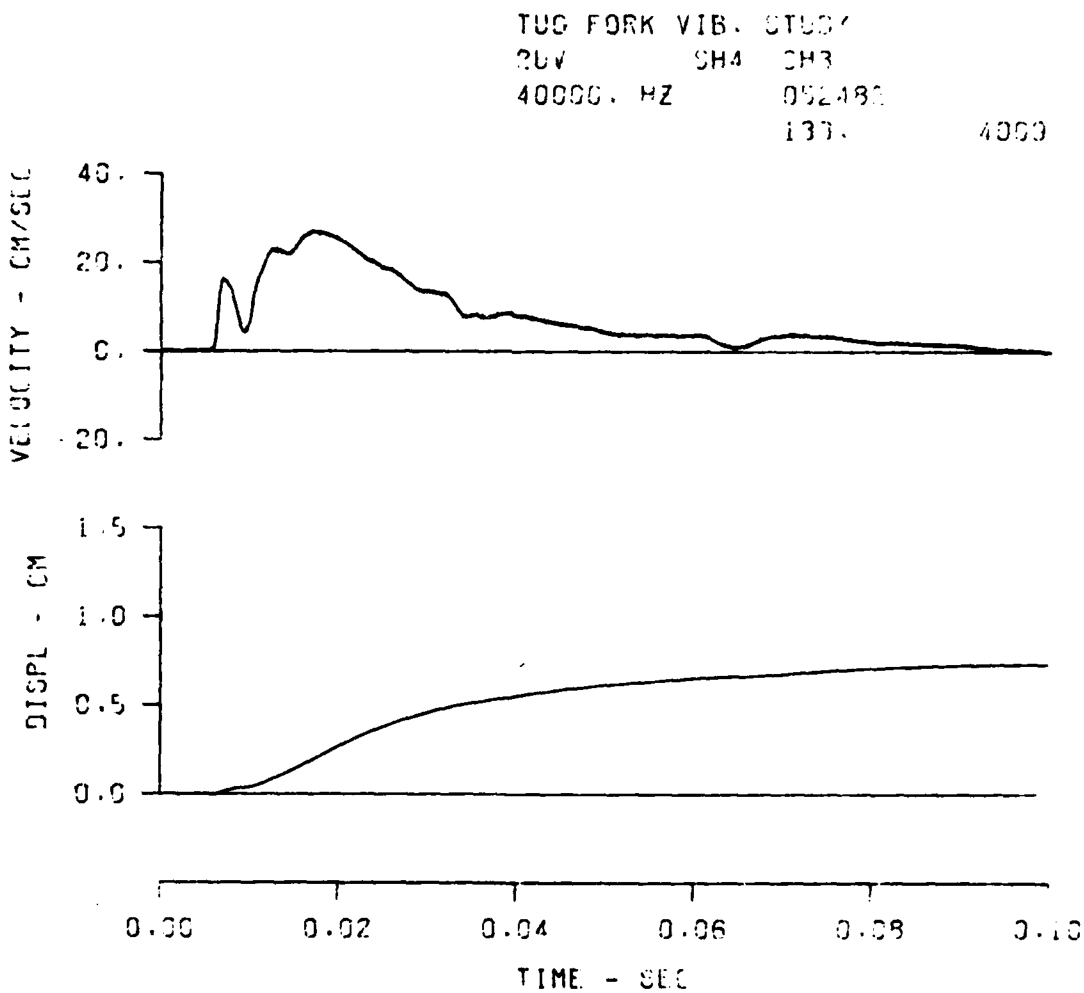

Figure D.3 Vertical particle velocity measurement and integration, gage canister on rock at 49.3 ft slant distance.

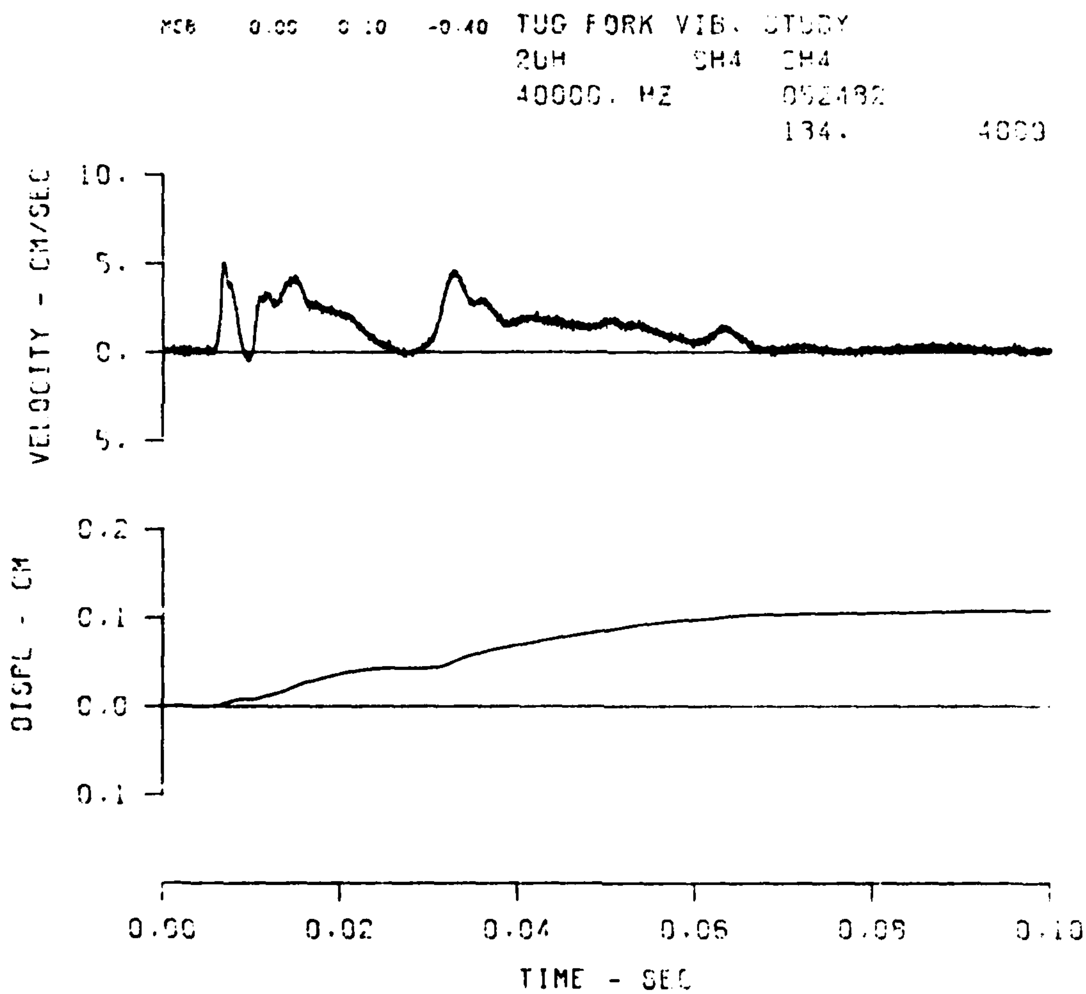

Figure D.4 Horizontal particle velocity measurement and integration, gage canister on rock at 49.3 ft slant distance.

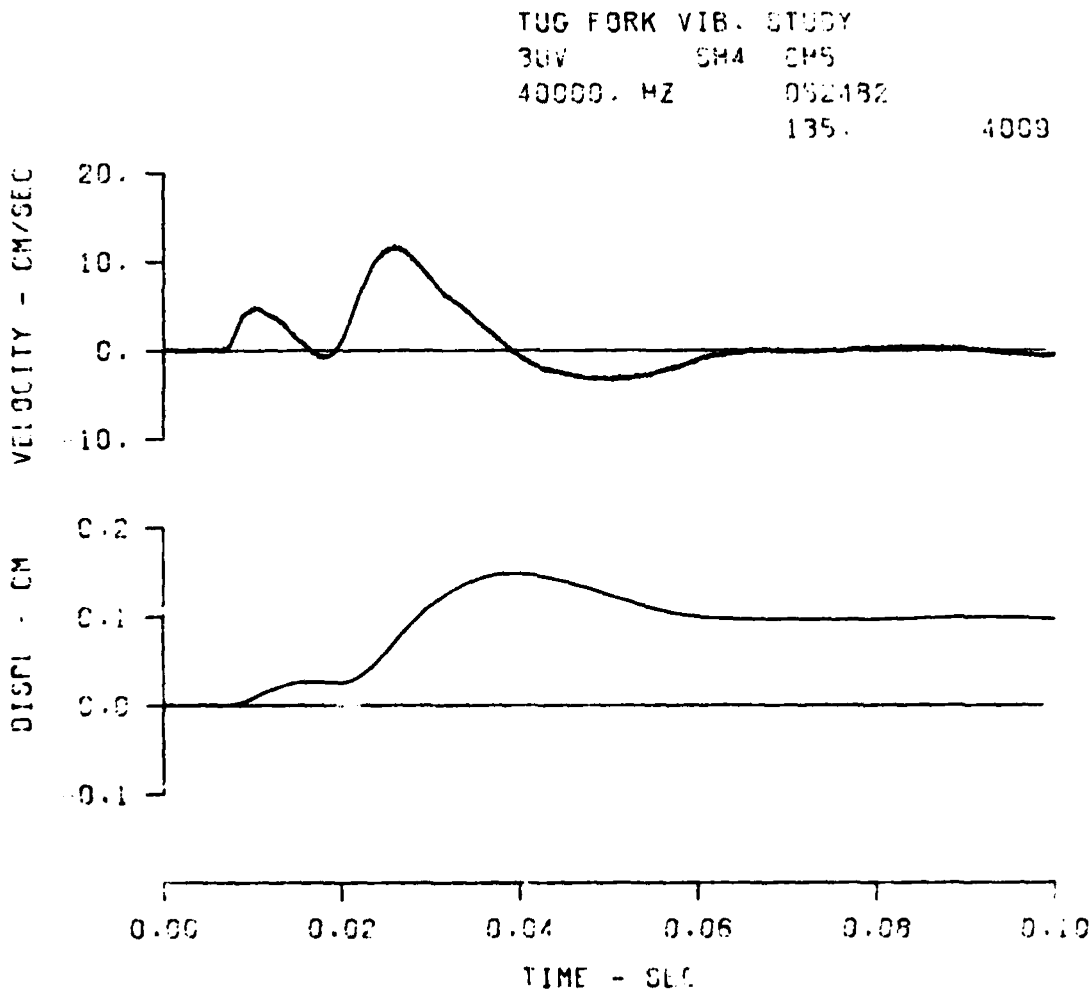

Figure D.5 Vertical particle velocity measurement and integration, gage canister on rock at 55.4 ft slant distance.

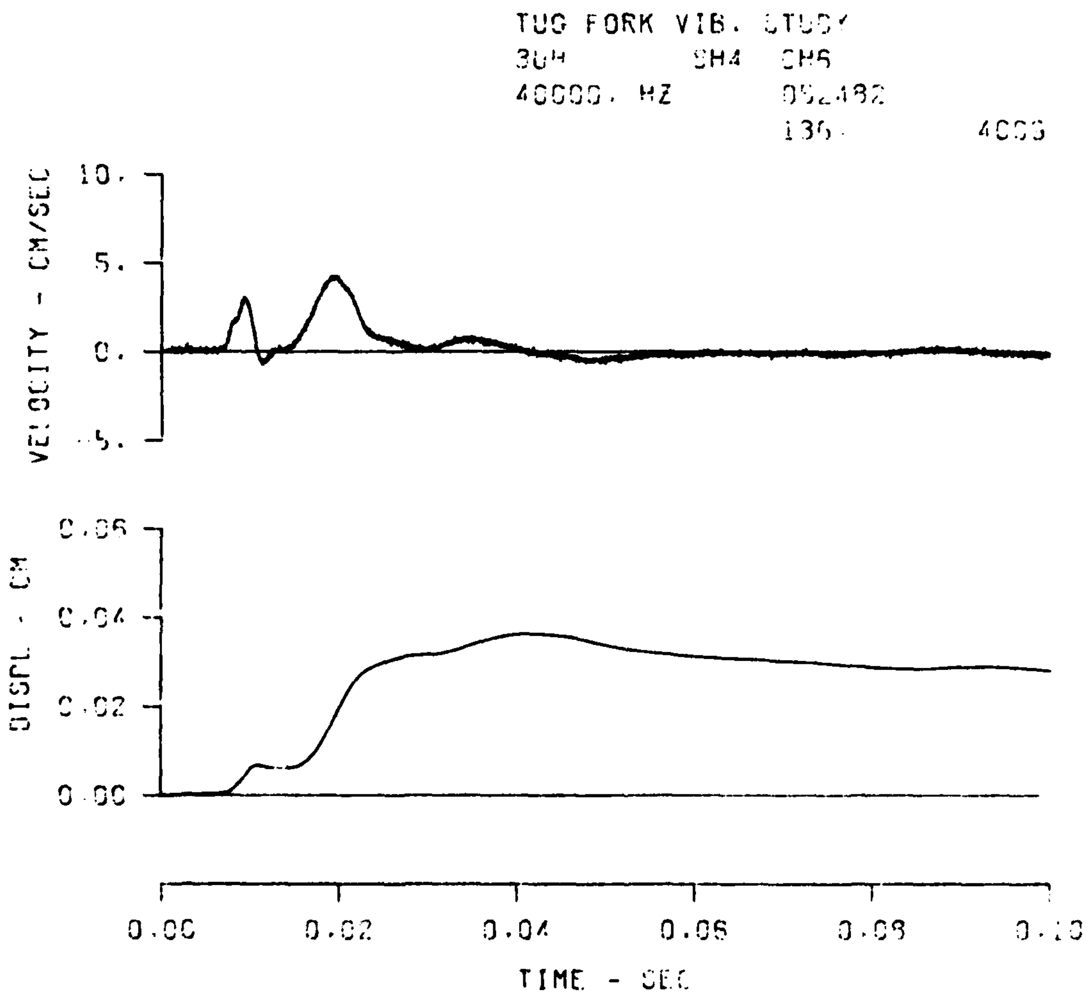

Figure D.6 Horizontal particle velocity measurement and integration, gage canister on rock at 55.4 ft slant distance.

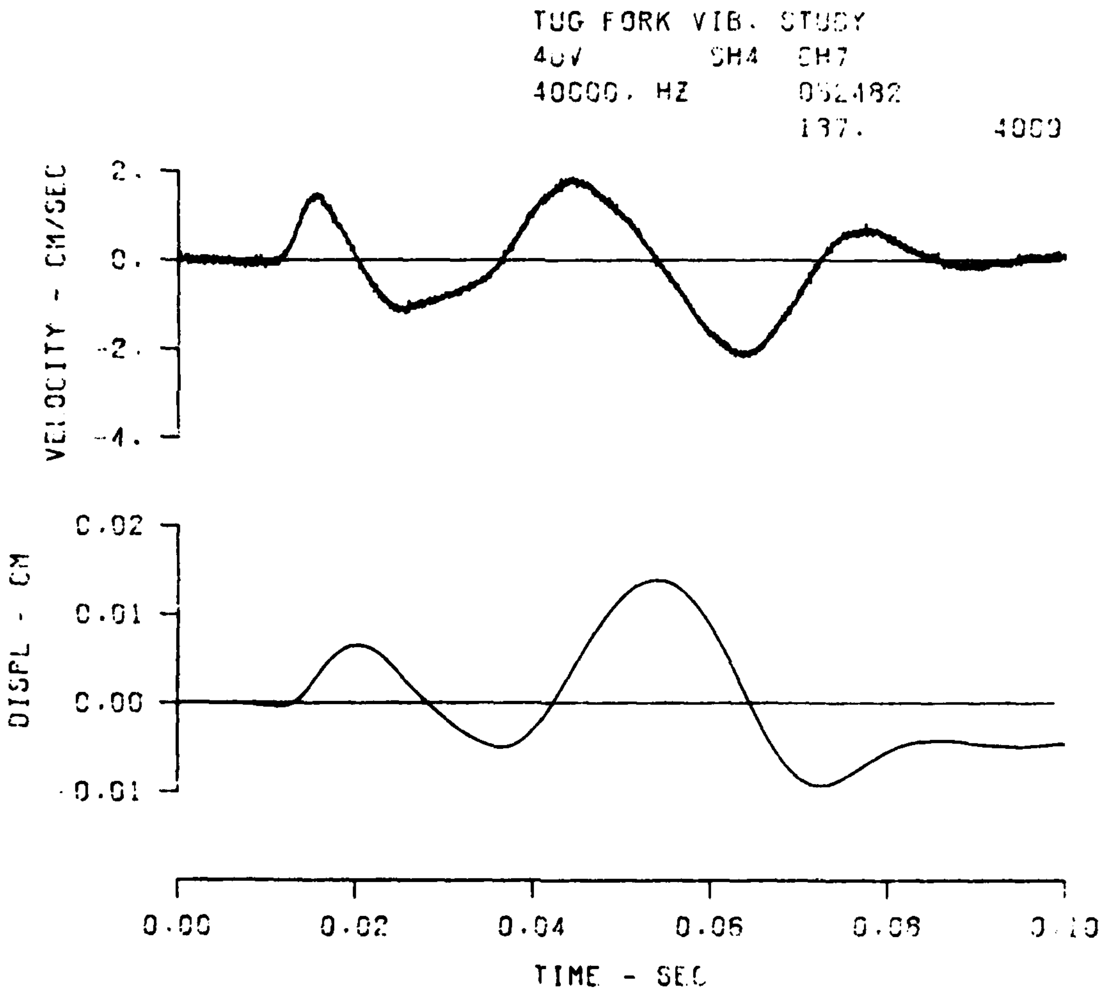

Figure D.7 **Vertical particle velocity measurement and integration, gage canister on rock at 84.3 ft slant distance.**

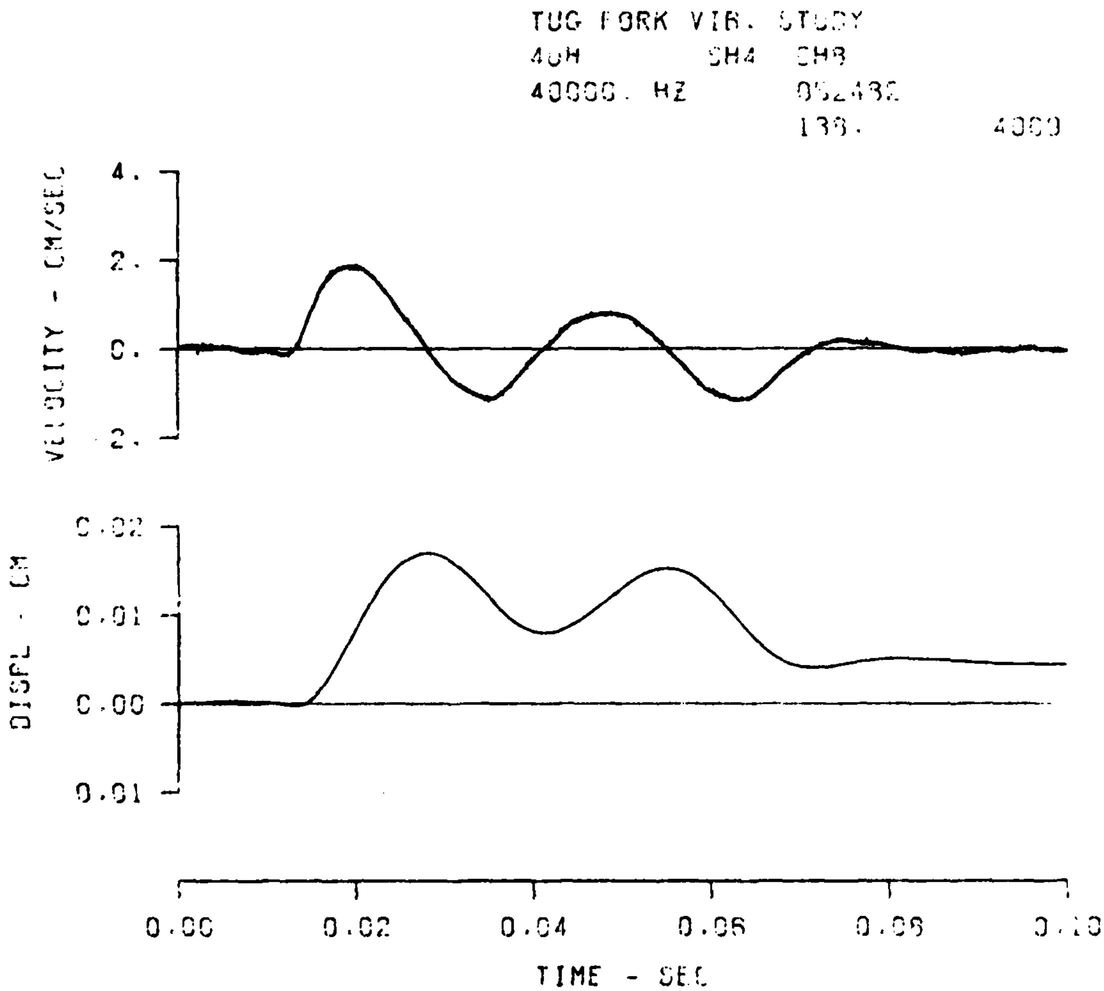

Figure D.8 Horizontal particle velocity measurement and integration, gage canister on rock at 84.2 ft slant distance.

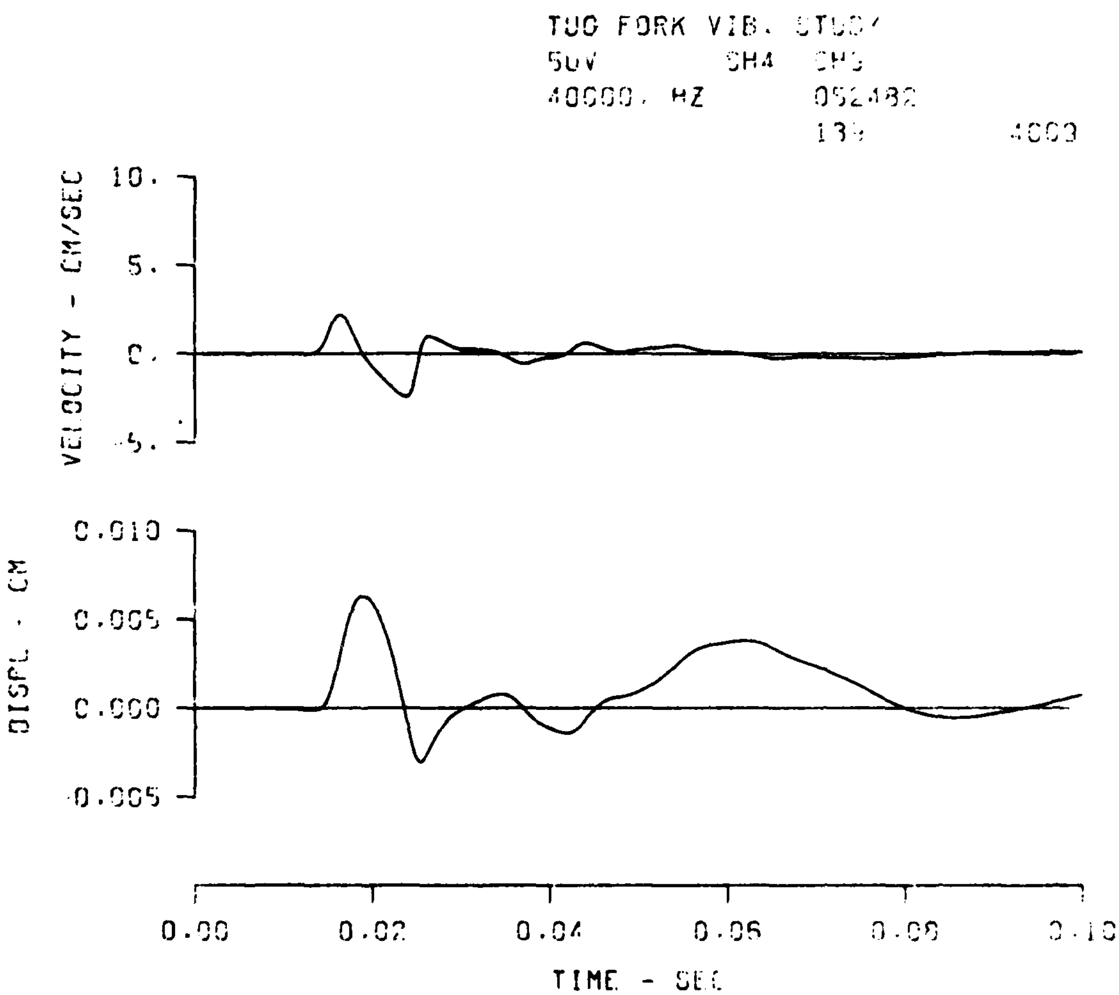

Figure D.9 Vertical particle velocity measurement and integration, gage canister on rock at 131 ft slant distance.

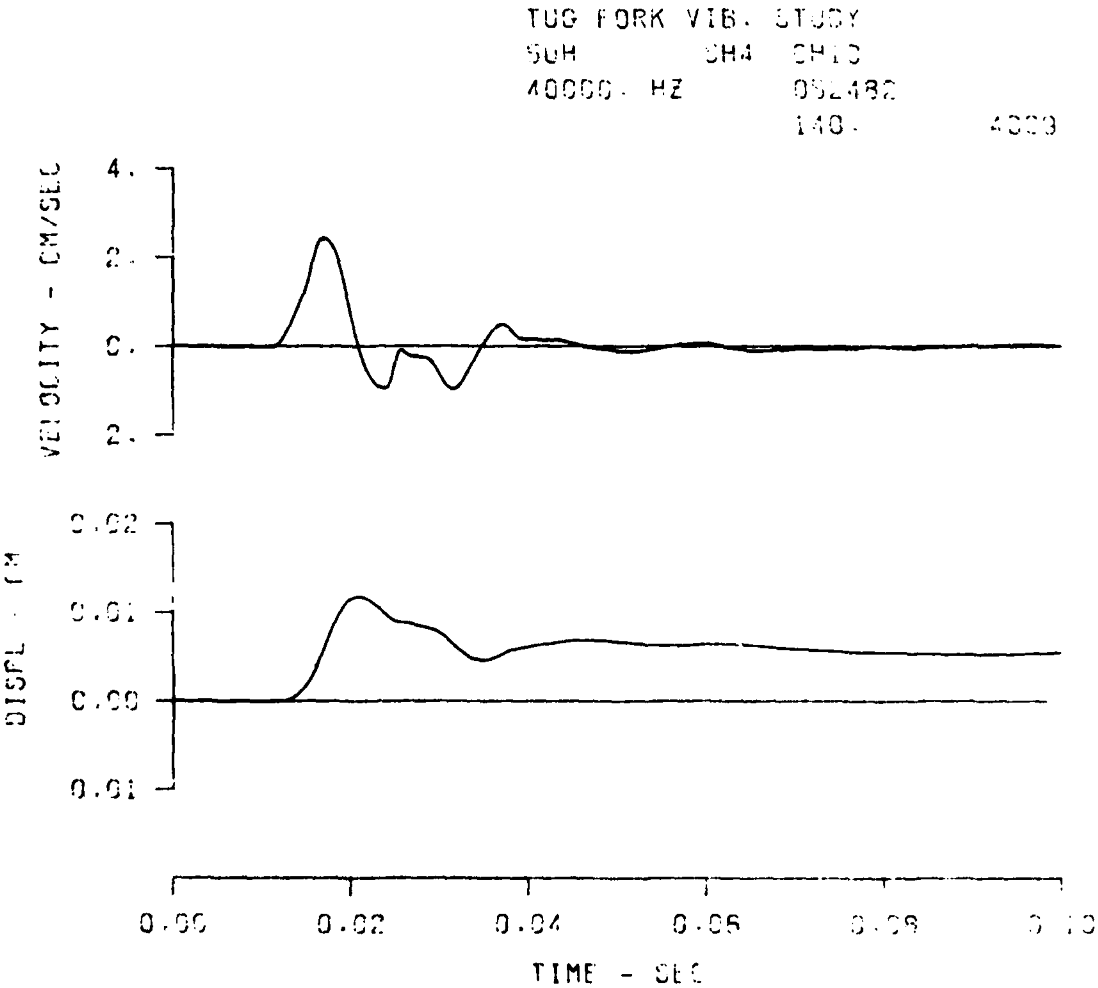

Figure D.10 Vertical particle velocity measurement and integration, gage canister on rock at 131 ft slant distance.

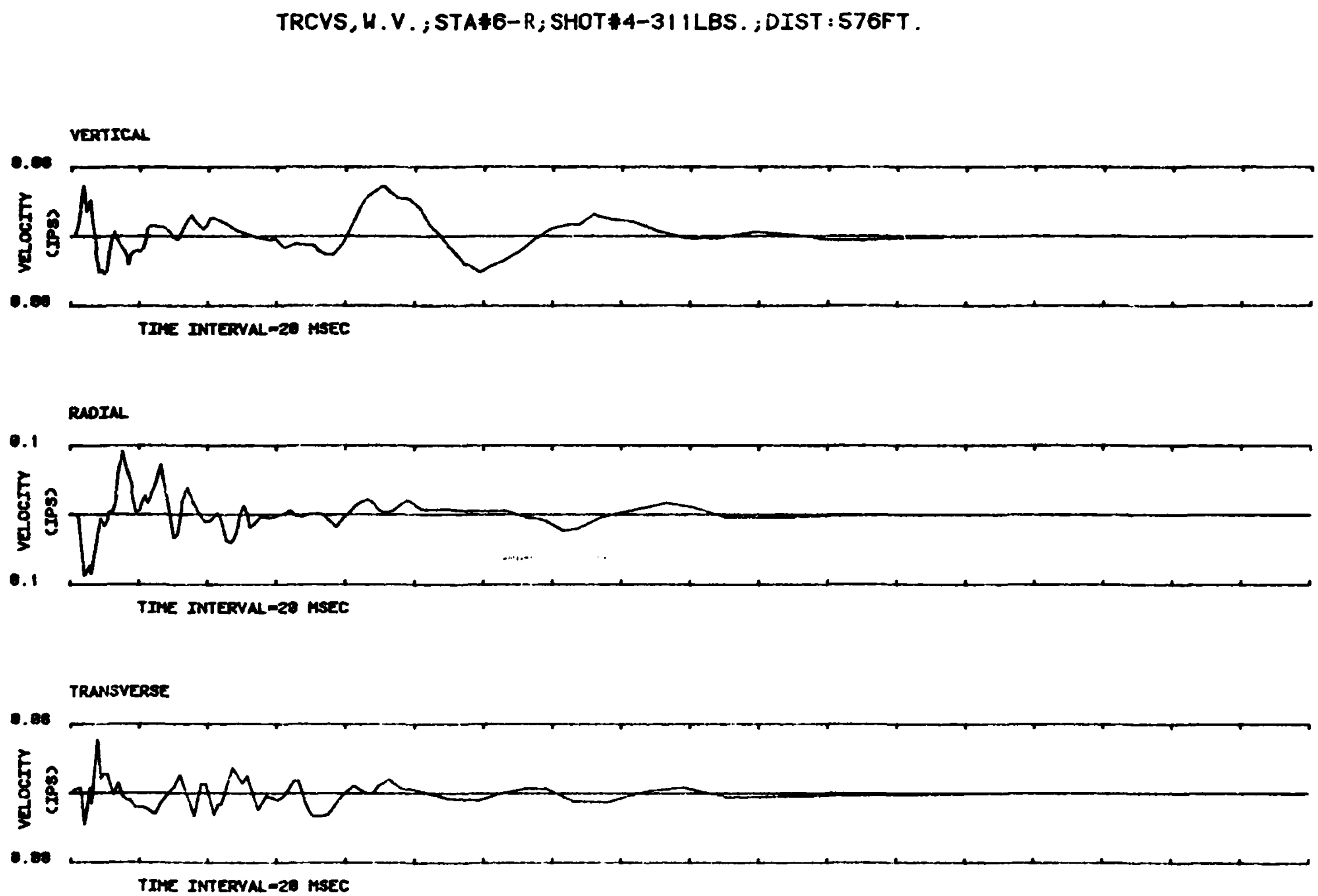

Figure D.11 Vertical, radial and transverse particle velocity measurements, gage canister on rock at 576 ft slant distance.

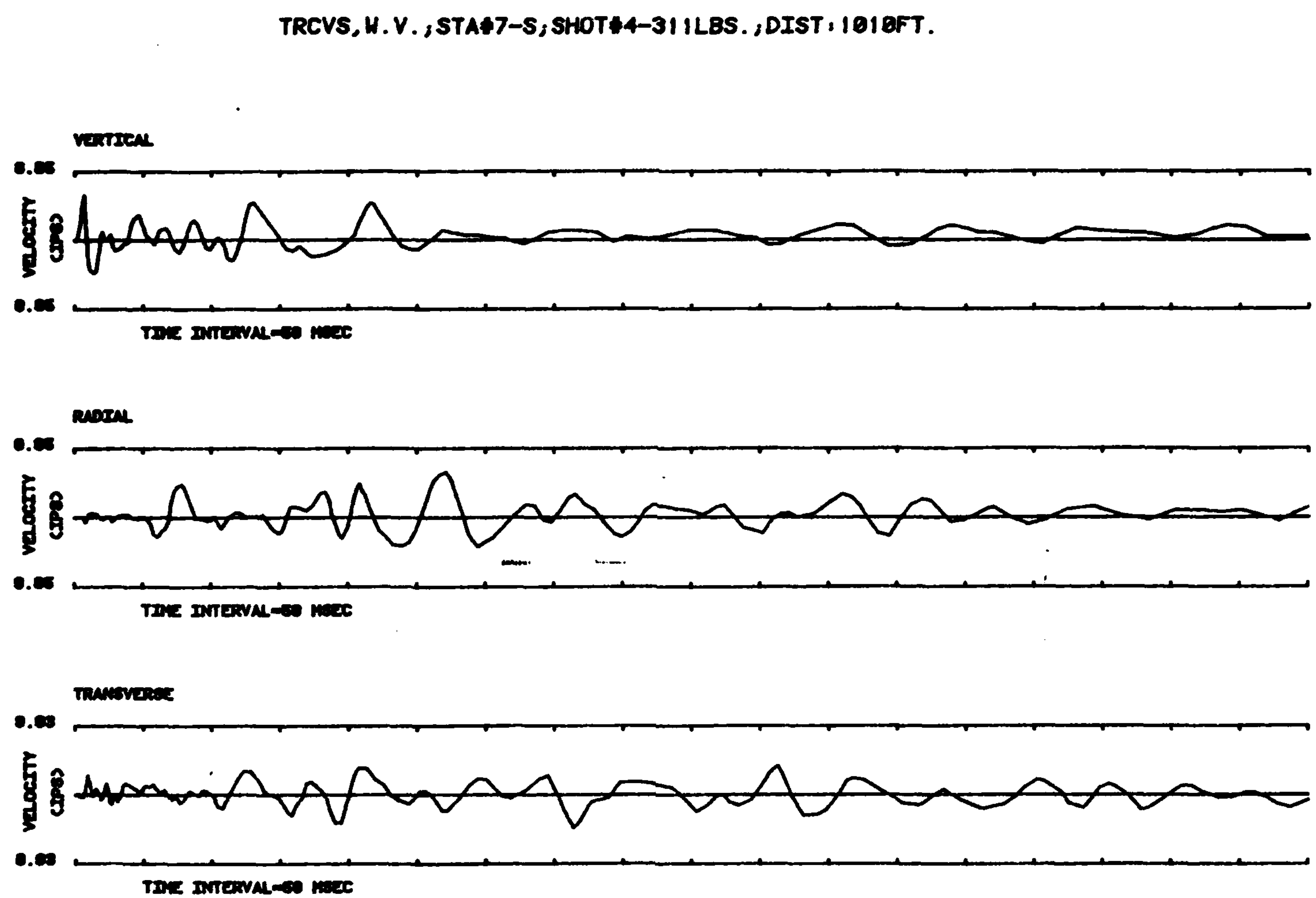

Figure D.12 Vertical, radial and transverse particle velocity measurements, gage canister in soil at 1010 ft slant distance.

TRCVS,W.V.;STA#10-F;SHOT 4-311LBS;DIST.   1986FT.

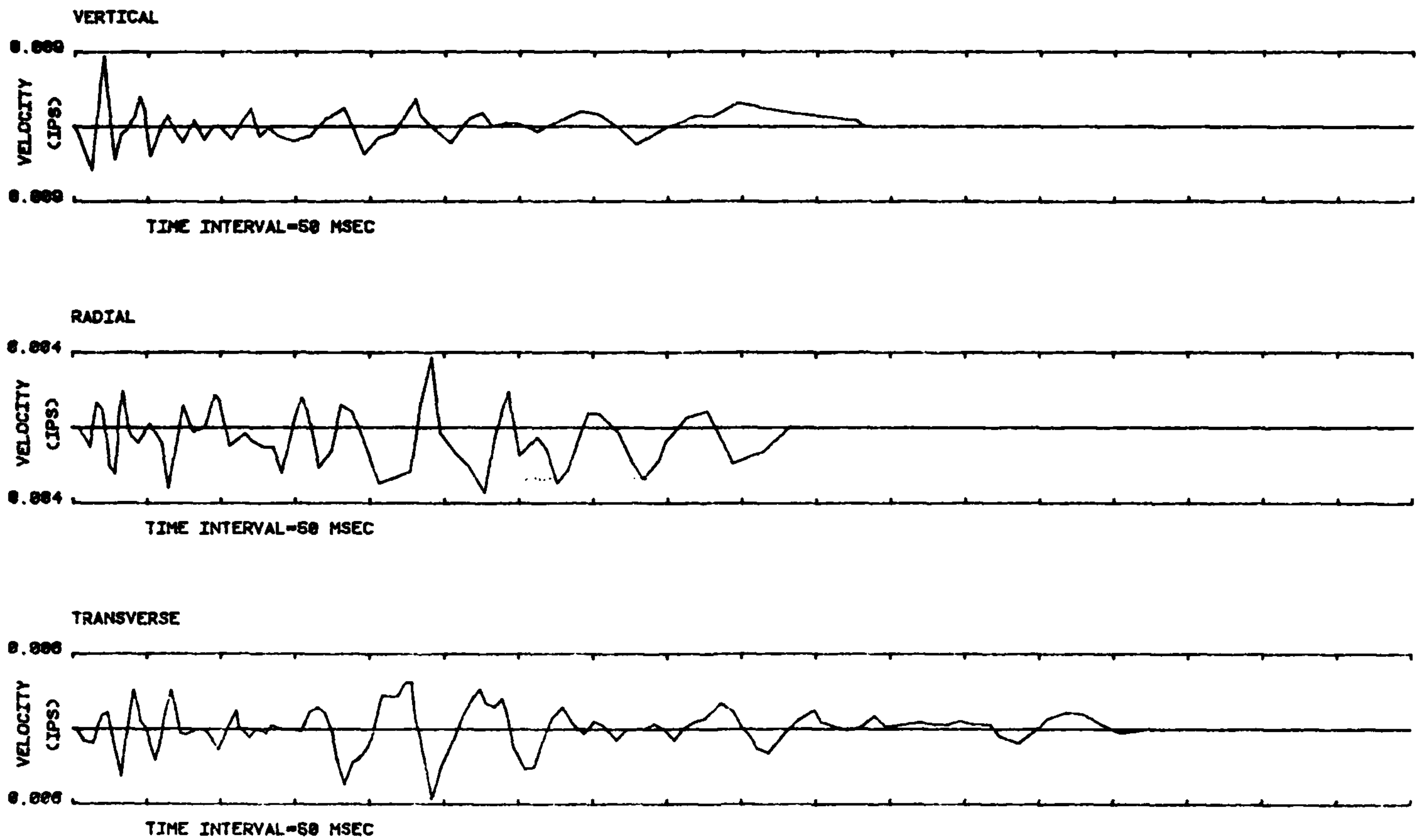

Figure D.13 Vertical, radial and transverse particle velocity measurements, gage canister on concrete slab (rock) at 1986 ft slant distance.

TRCVS,W.V.;STA#11-R;SHOT 4-311LBS;DIST. 1988FT.

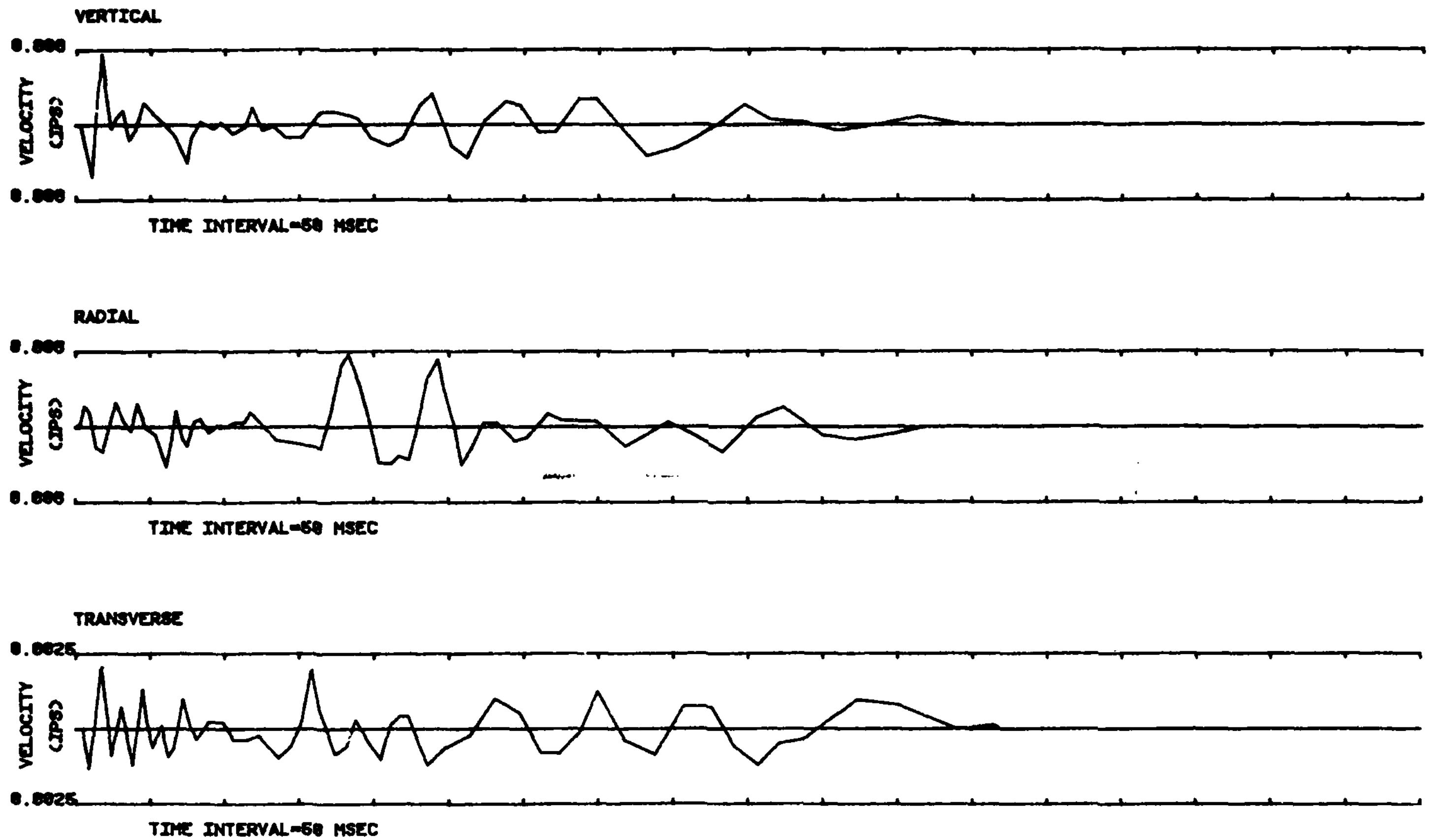

Figure D.14 Vertical, radial and transverse particle velocity measurements, gage canister on rock at 1988 ft slant distance.

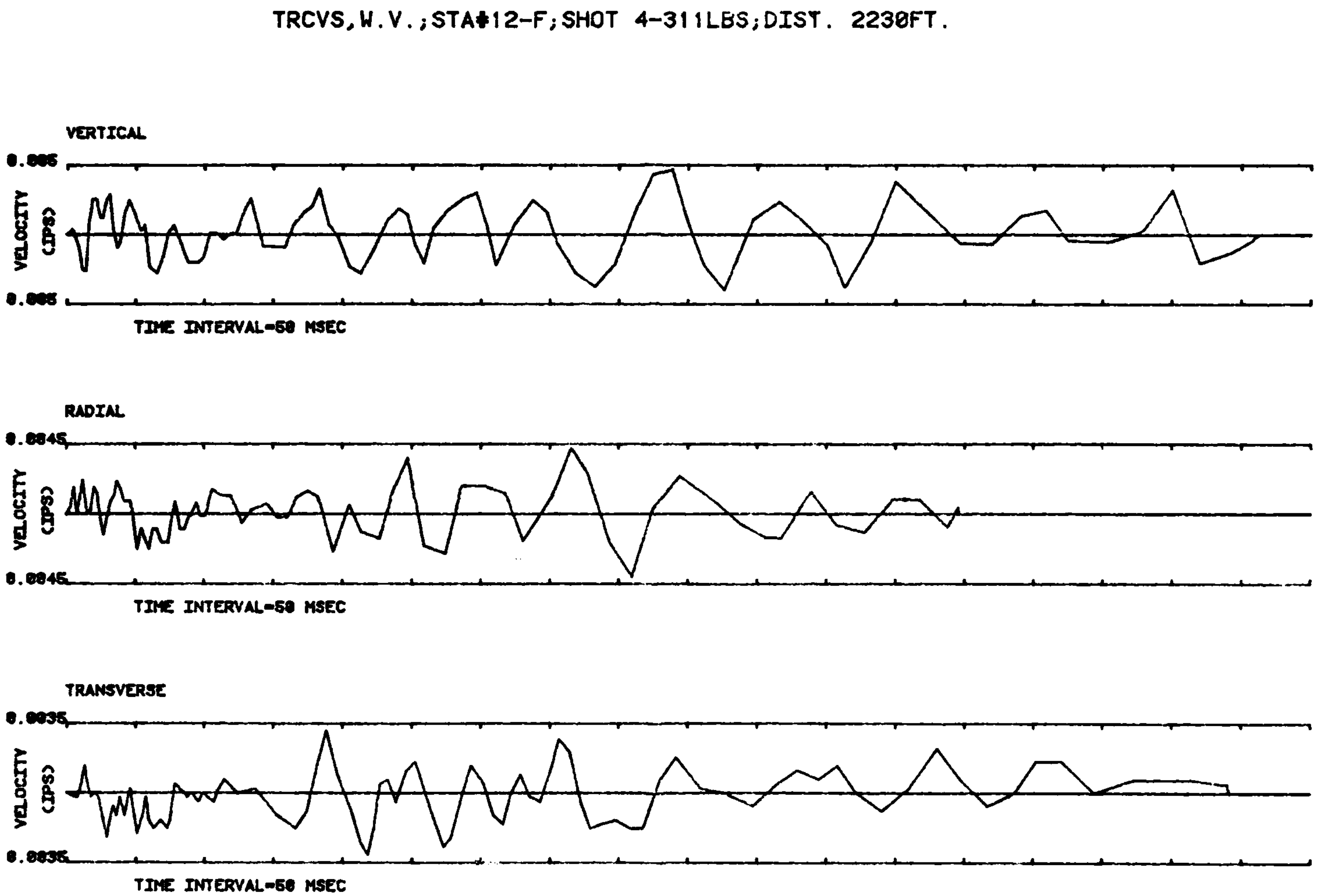

Figure D.15 Vertical, radial and transverse particle velocity measurements, gage canister on concrete slab (foundation, rock) at 2230 ft slant distance.

TRCVS,W.V.;STA#13-B;SHOT 4-311LBS;DIST. 2258FT.

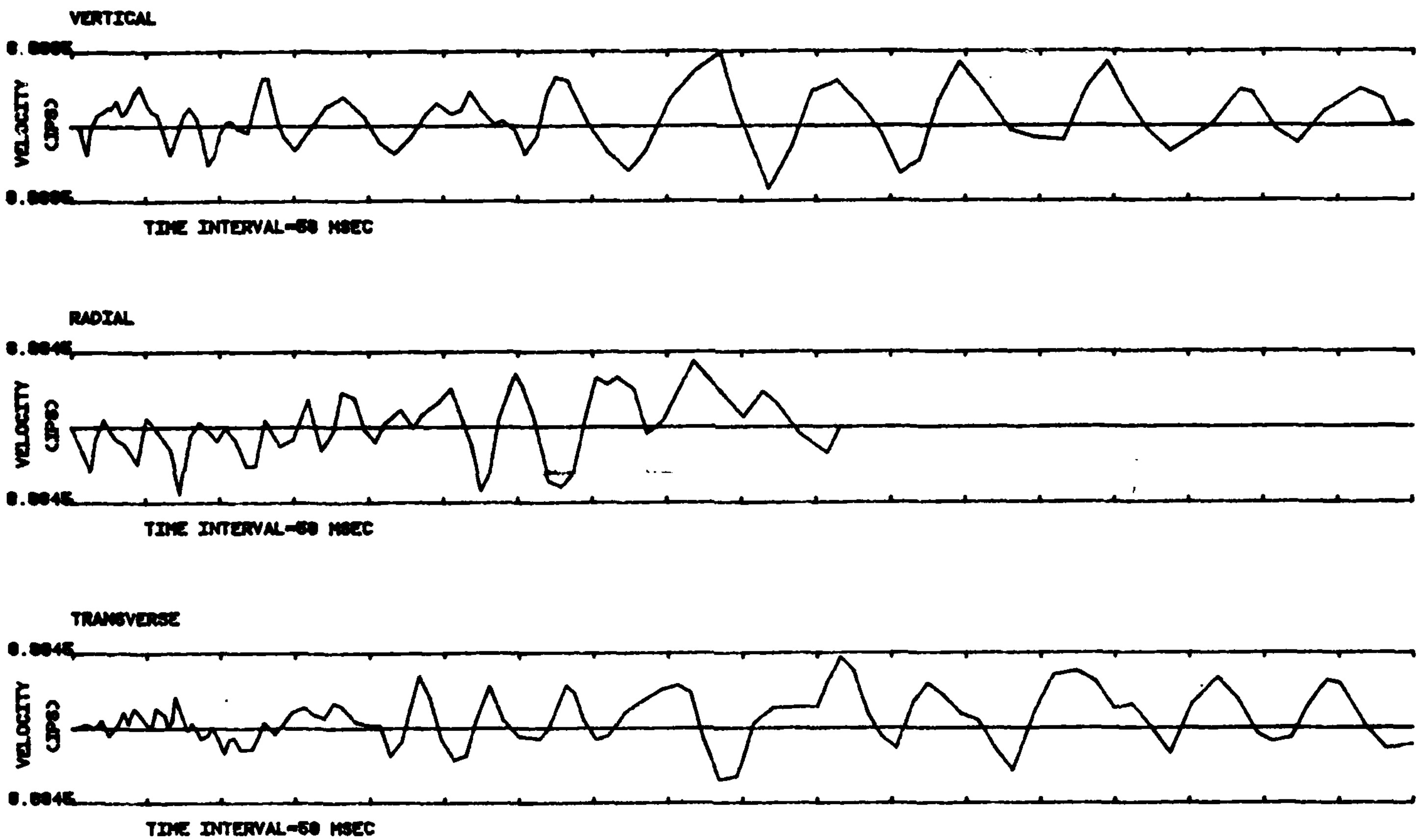

Figure D.16 Vertical, radial and transverse particle velocity measurements, gage canister on concrete slab (6th floor) at 2258 ft slant distance.

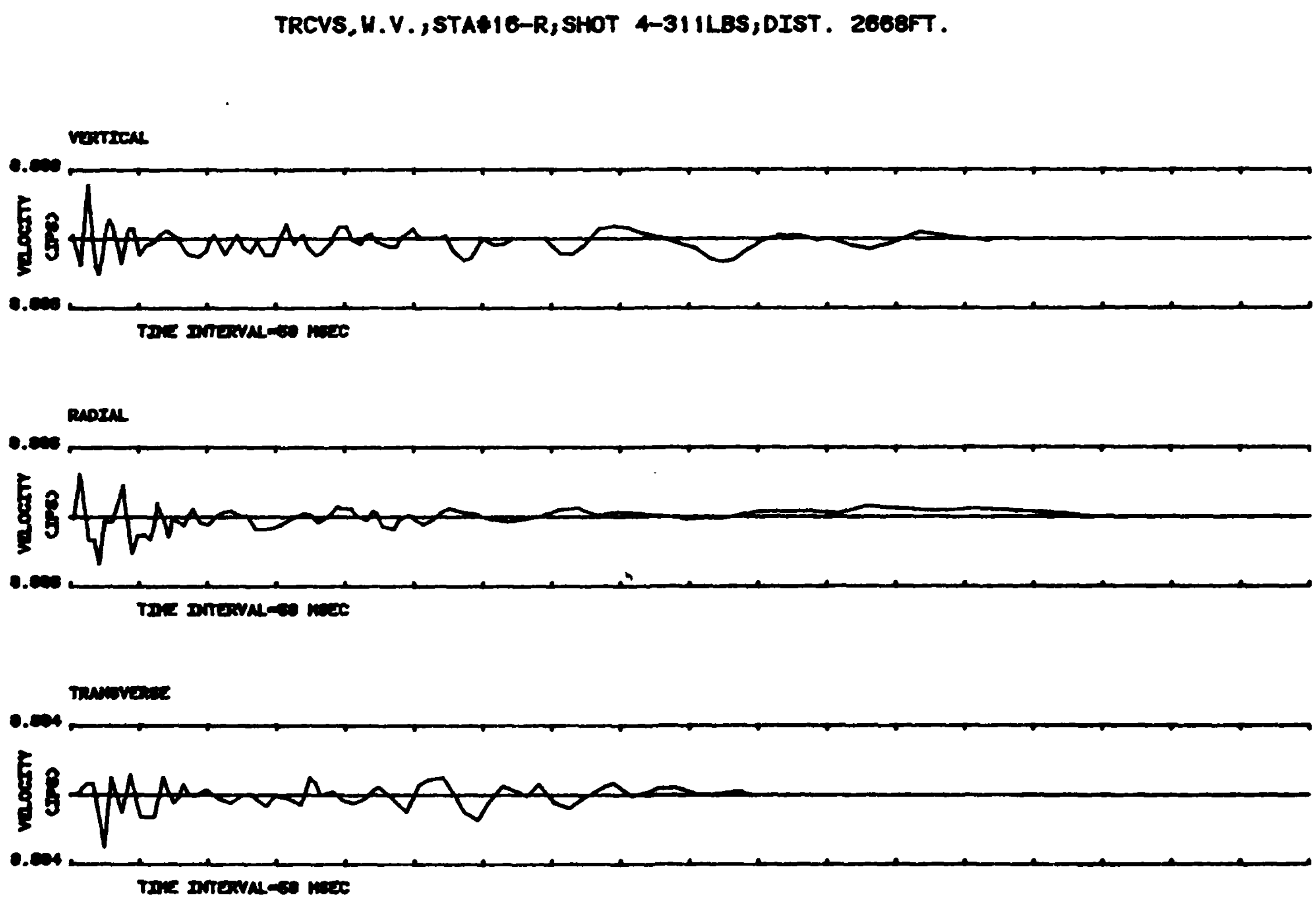

Figure D.17 Vertical, radial and transverse particle velocity measurements, gage canister on tunnel liner (rock) at 2668 ft slant distance.

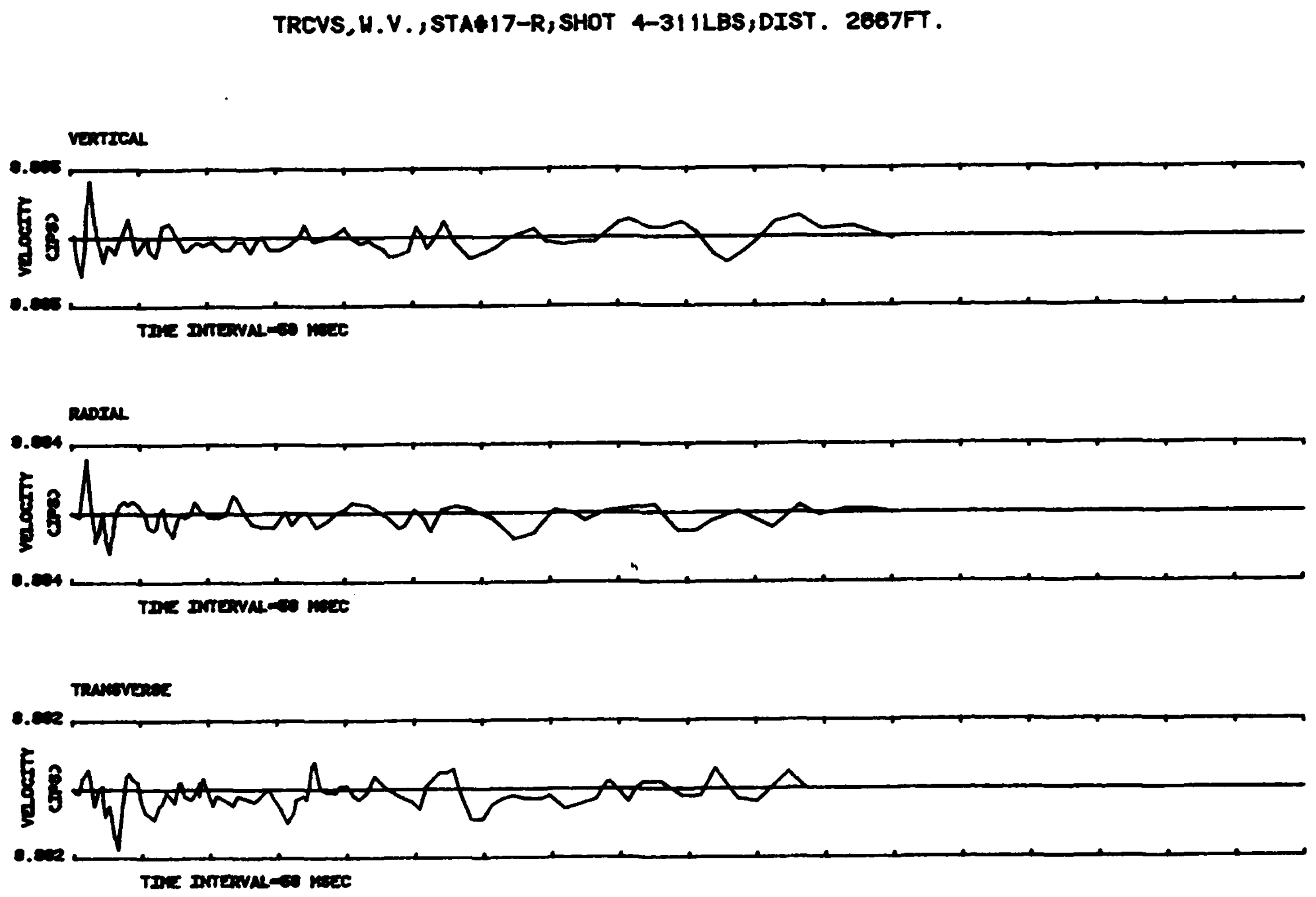

Figure D.18 Vertical, radial and transverse particle velocity measurements, gage canister in unlined tunnel (rock) at 2667 ft slant distance.

APPENDIX E

Shot No. 5

TOTAL CHARGE WEIGHT 328 lbs

Prilled Ammonium Nitrate

VELOCITY- AND DISPLACEMENT-TIME HISTORIES

In the ground motion histories in this Appendix (Figures E.1 through E.18), upward trace deflections indicate upward motions for vertical gages and outward motions for horizontal or radial gages.

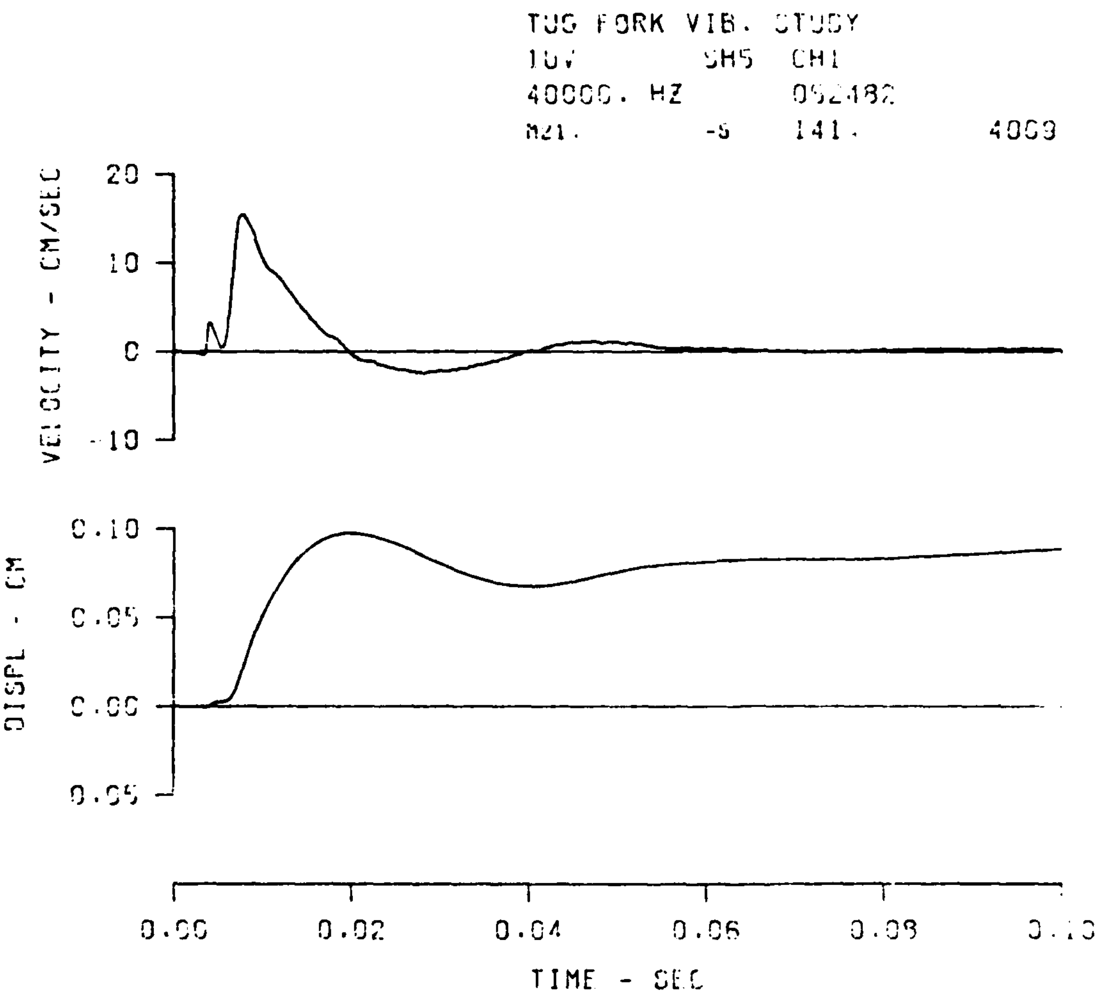

Figure E.1 Vertical particle velocity measurement and integration, gage canister on rock at 59.1 ft slant distance.

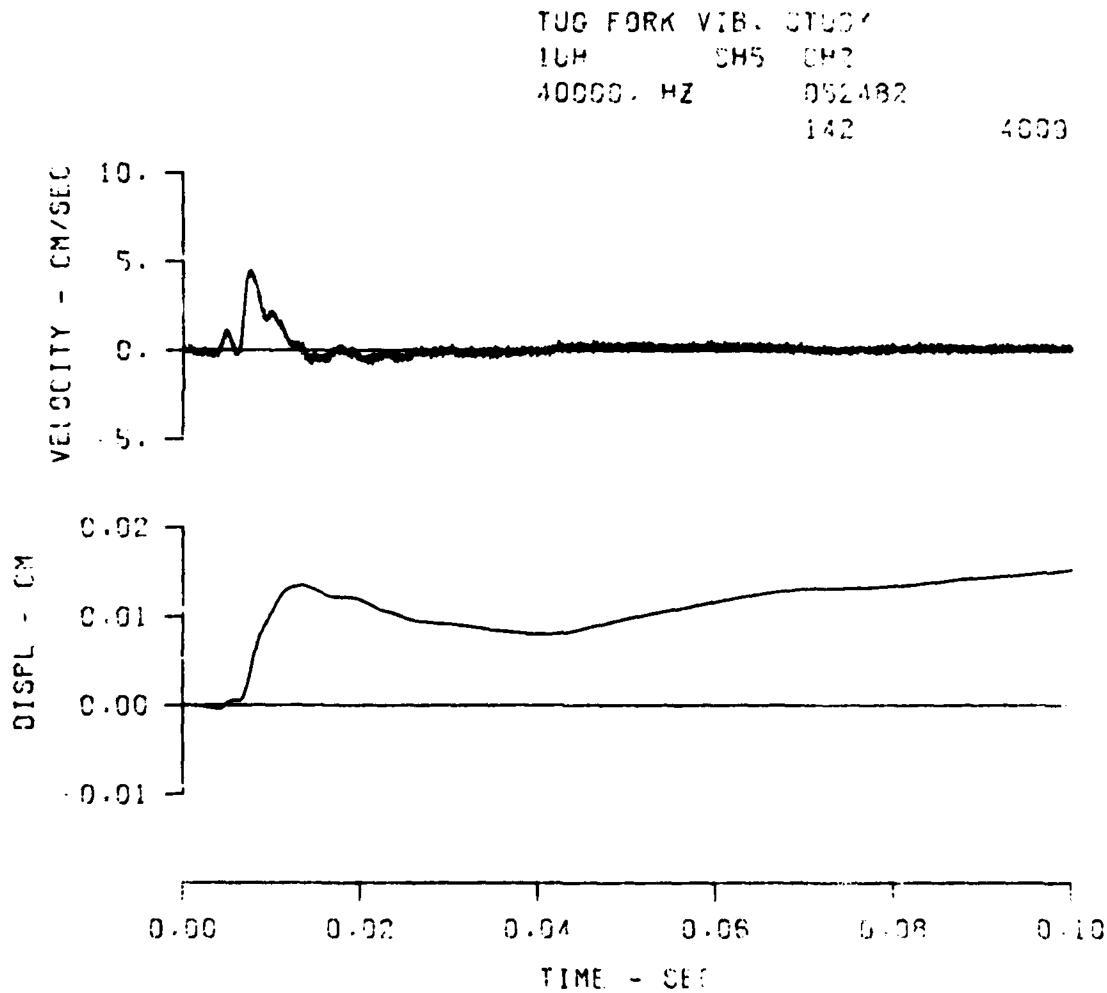

Figure E.2 Horizontal particle velocity measurement and integration, gage canister on rock at 59.1 ft slant distance.

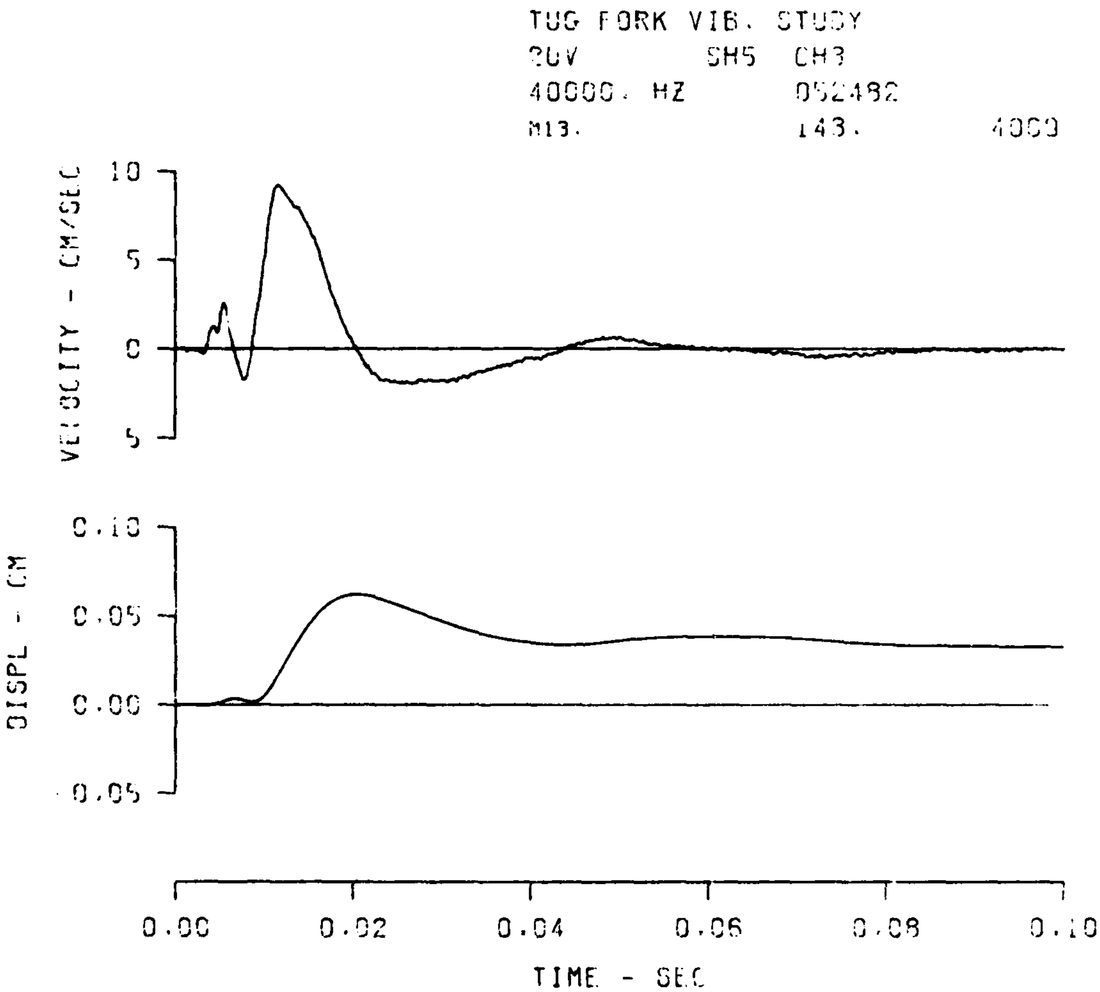

Figure E.3 Vertical particle velocity measurement and integration, gage canister on rock at 58.1 ft slant distance.

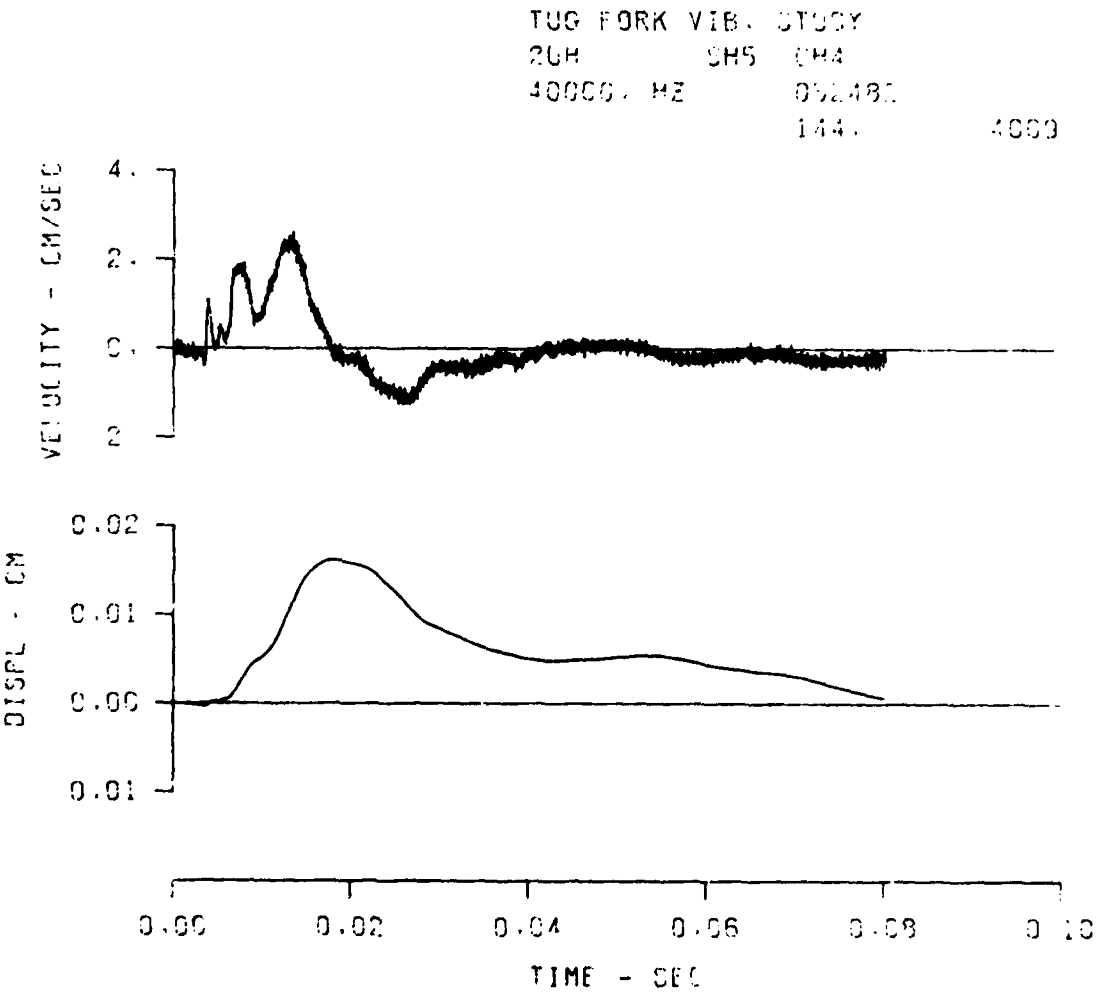

Figure E.4 Horizontal particle velocity measurement and integration, gage canister on rock at 58.1 ft slant distance.

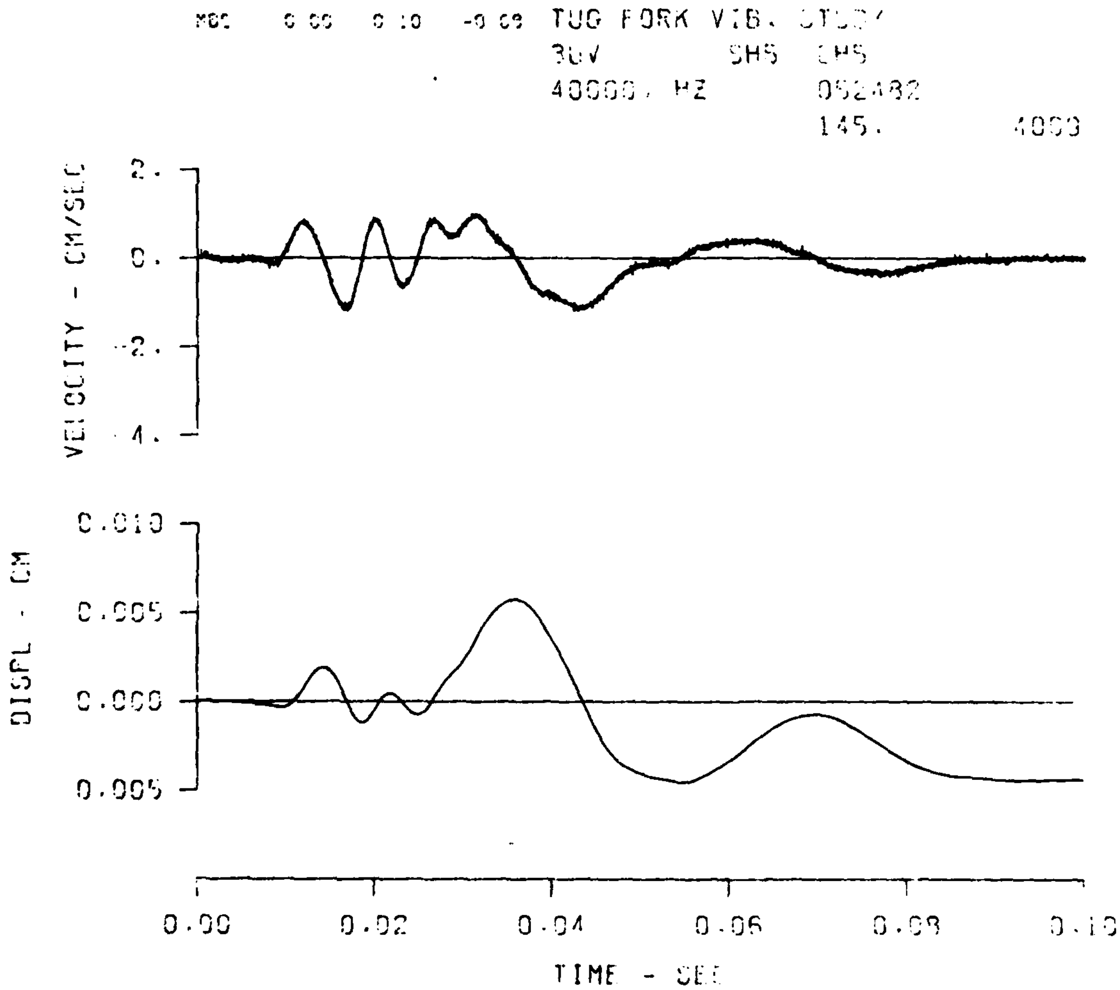

Figure E.5 Vertical particle velocity measurement and integration, gage canister on rock at 78.3 ft slant distance.

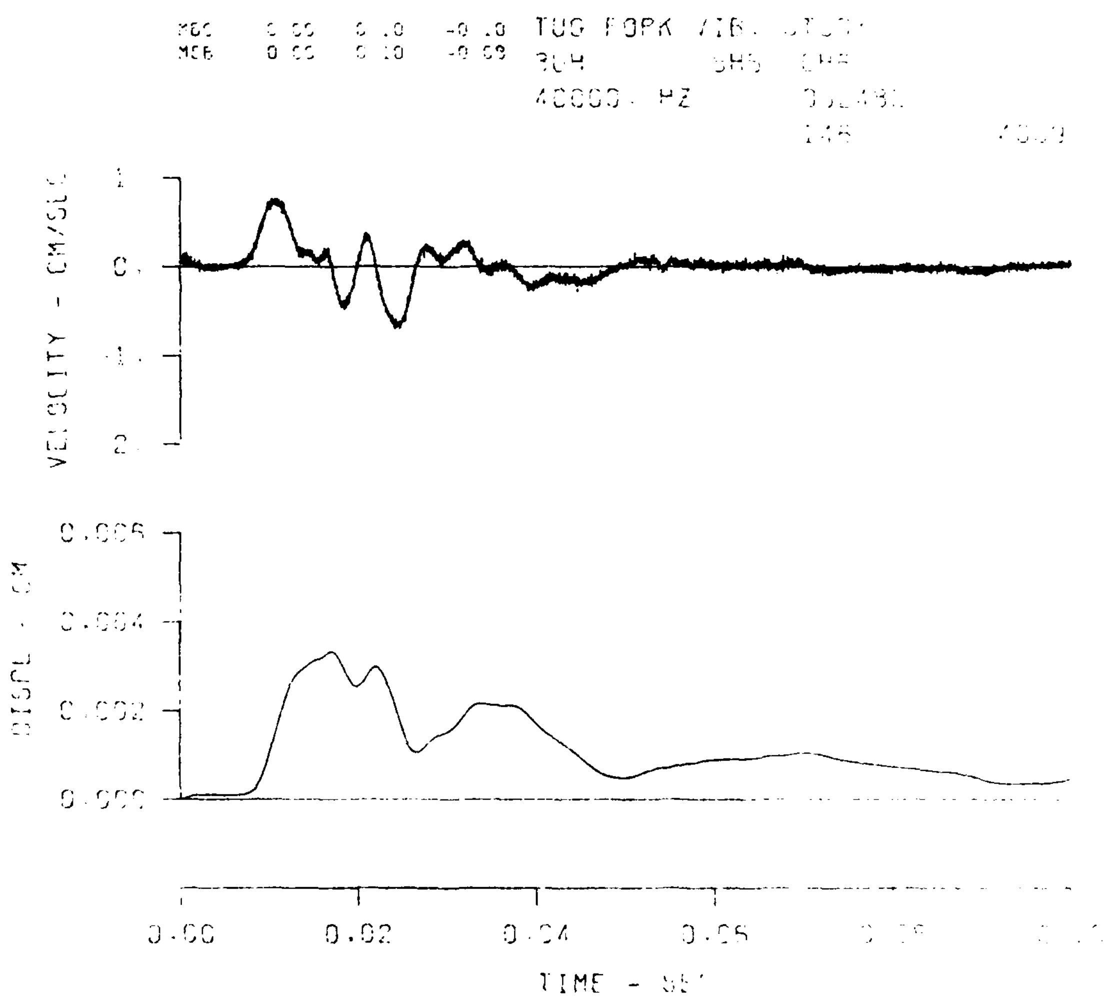

Figure E.6 Horizontal particle velocity measurments and integration, gage canister on rock at 78.3 ft slant distance.

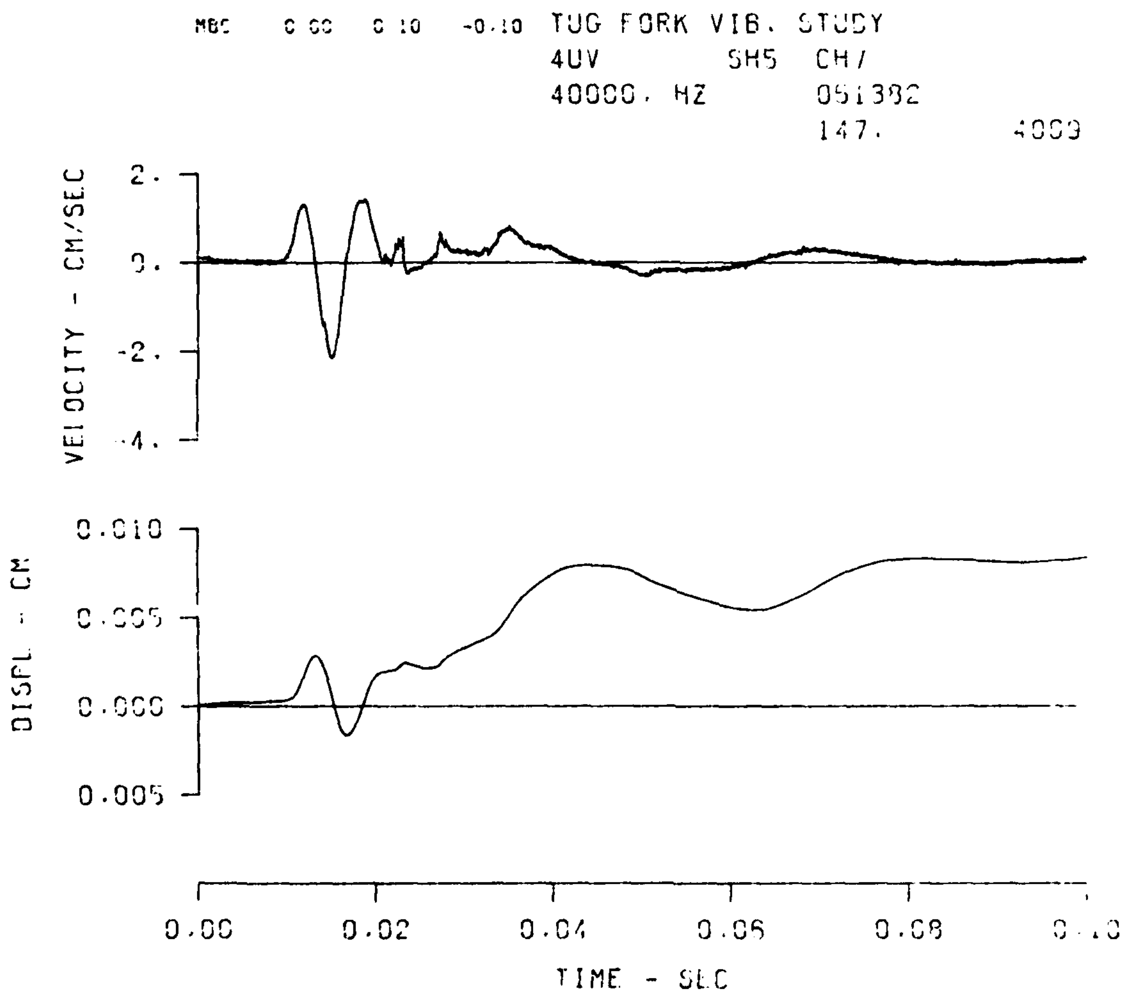

Figure E.7 Vertical particle velocity measurement and integration, gage canister on rock at 105 ft slant distance.

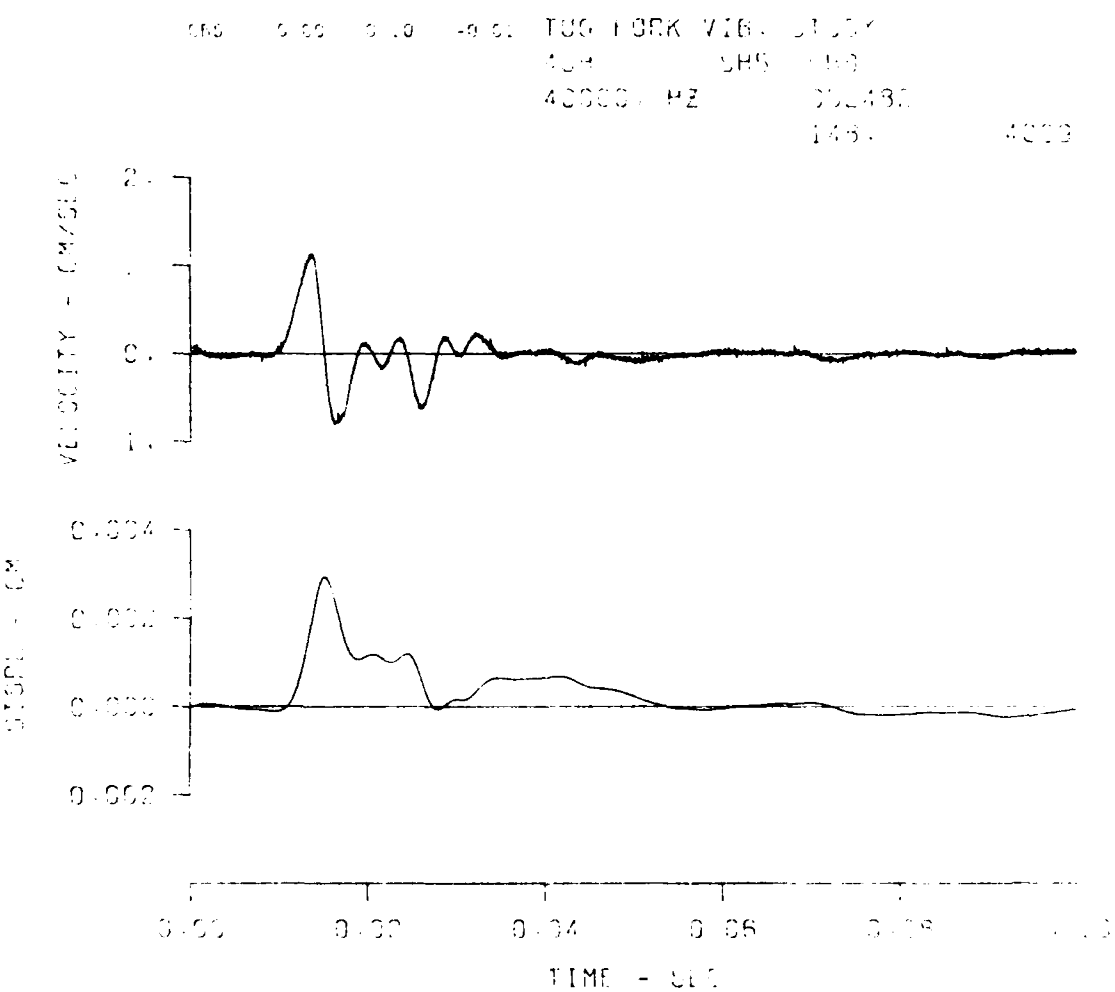

Figure E.8 Horizontal particle velocity measurement and integration, gage canister on rock at 105 ft slant distance.

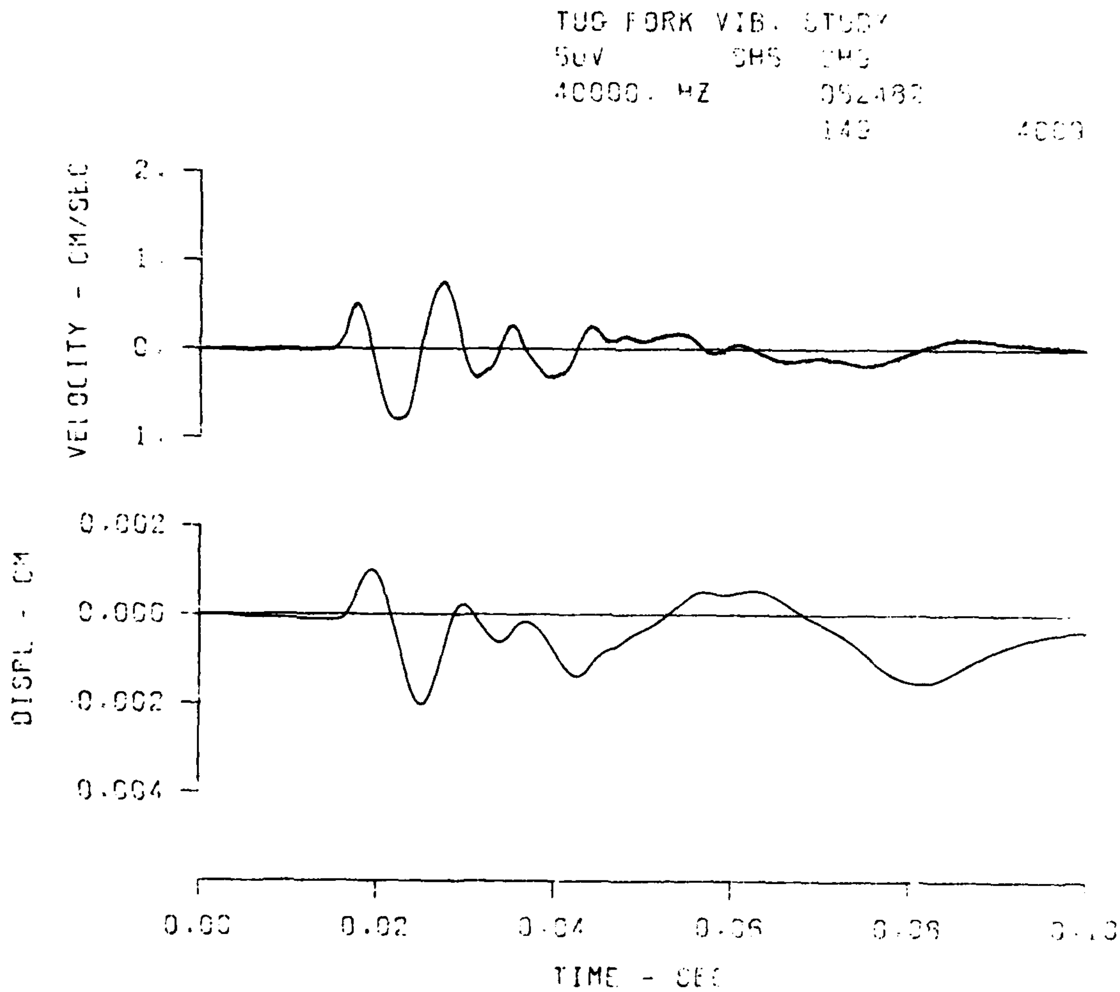

Figure E.9 Vertical particle velocity measurement and integration, gage canister on rock at 177 ft slant distance.

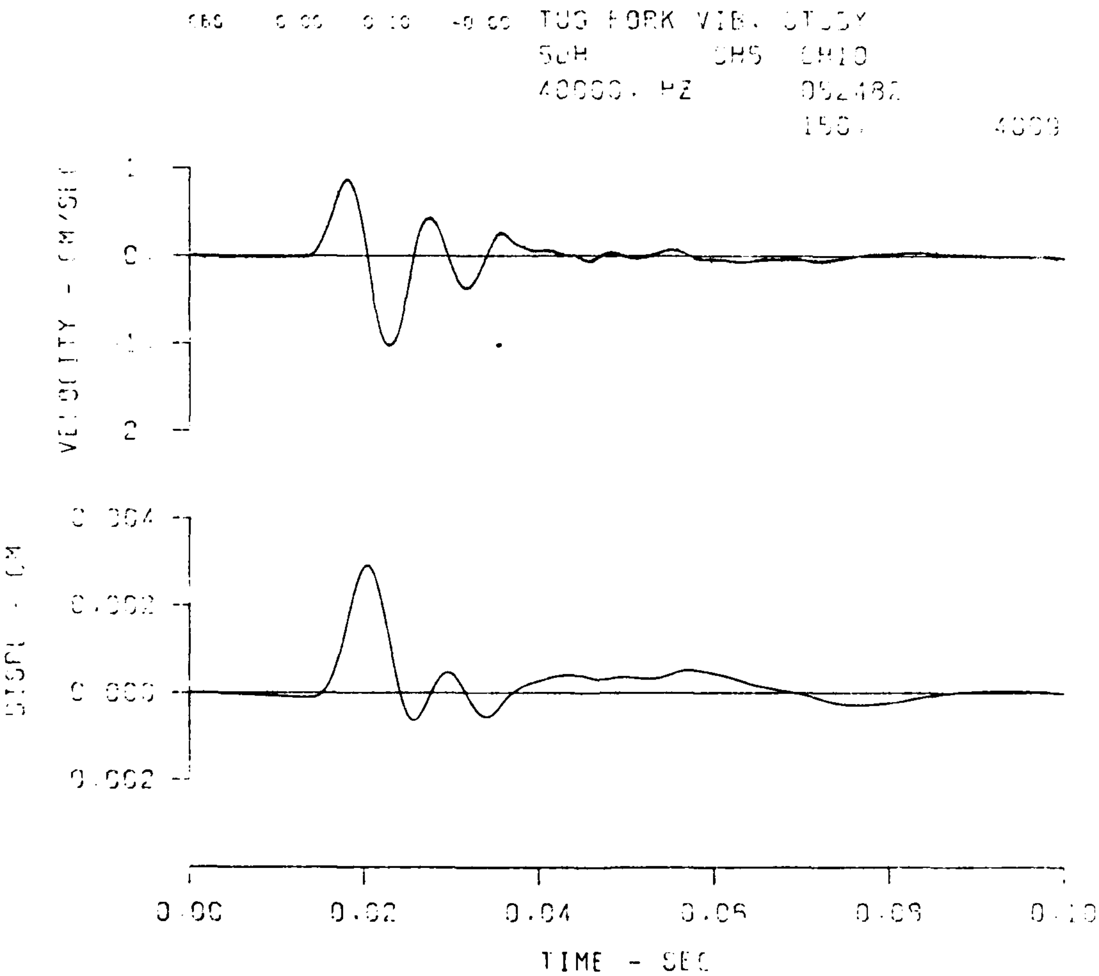

Figure E.10 Horizontal particle velocity measurement and integration, gage canister on rock at 177 ft slant distance.

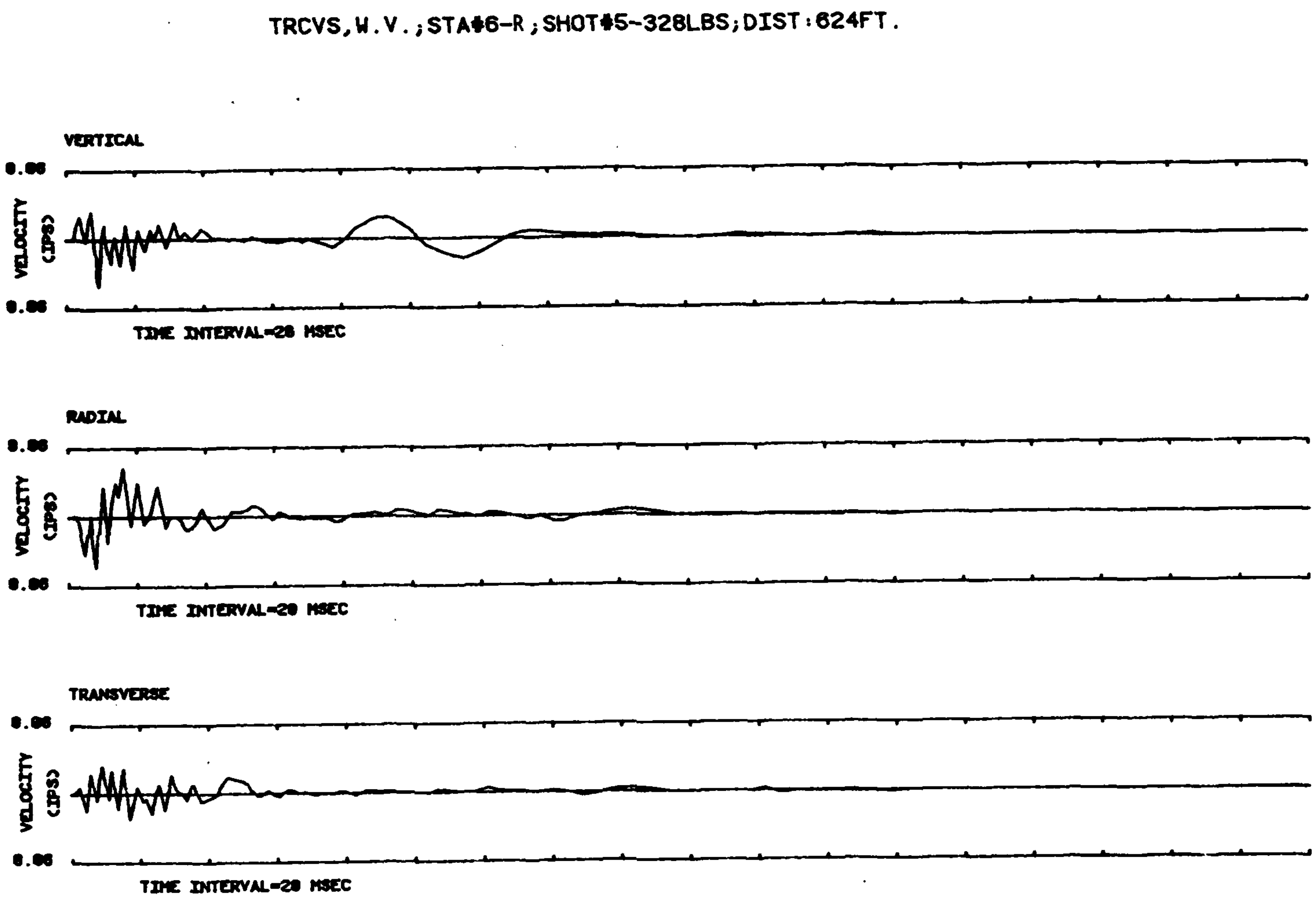

Figure E.11 Vertical, radial and transverse particle velocity measurements, gage canister on rock at 624 ft slant distance.

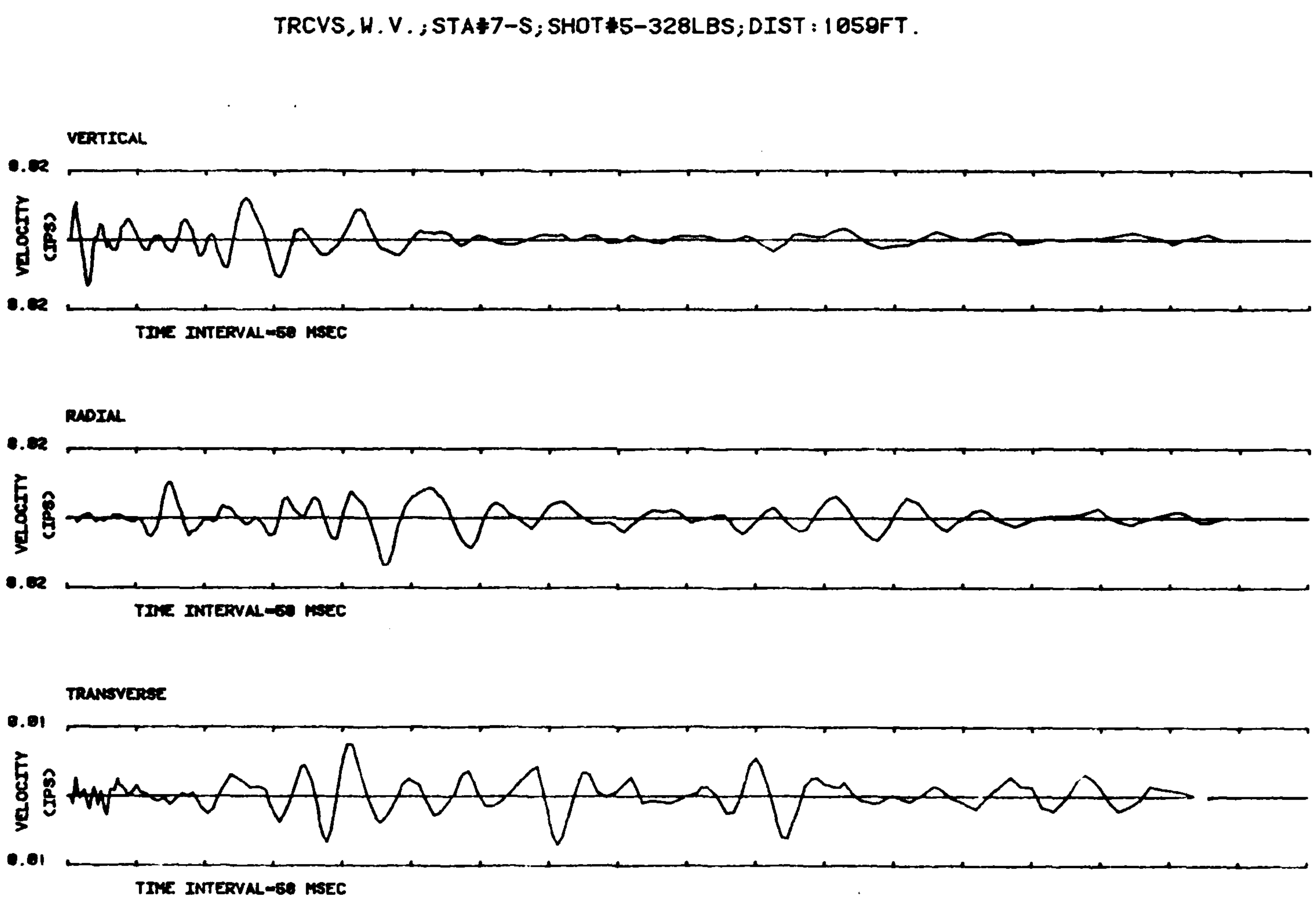

Figure E.12 Vertical, radial and transverse particle velocity measurements, gage canister in soil at 1059 ft slant distance.

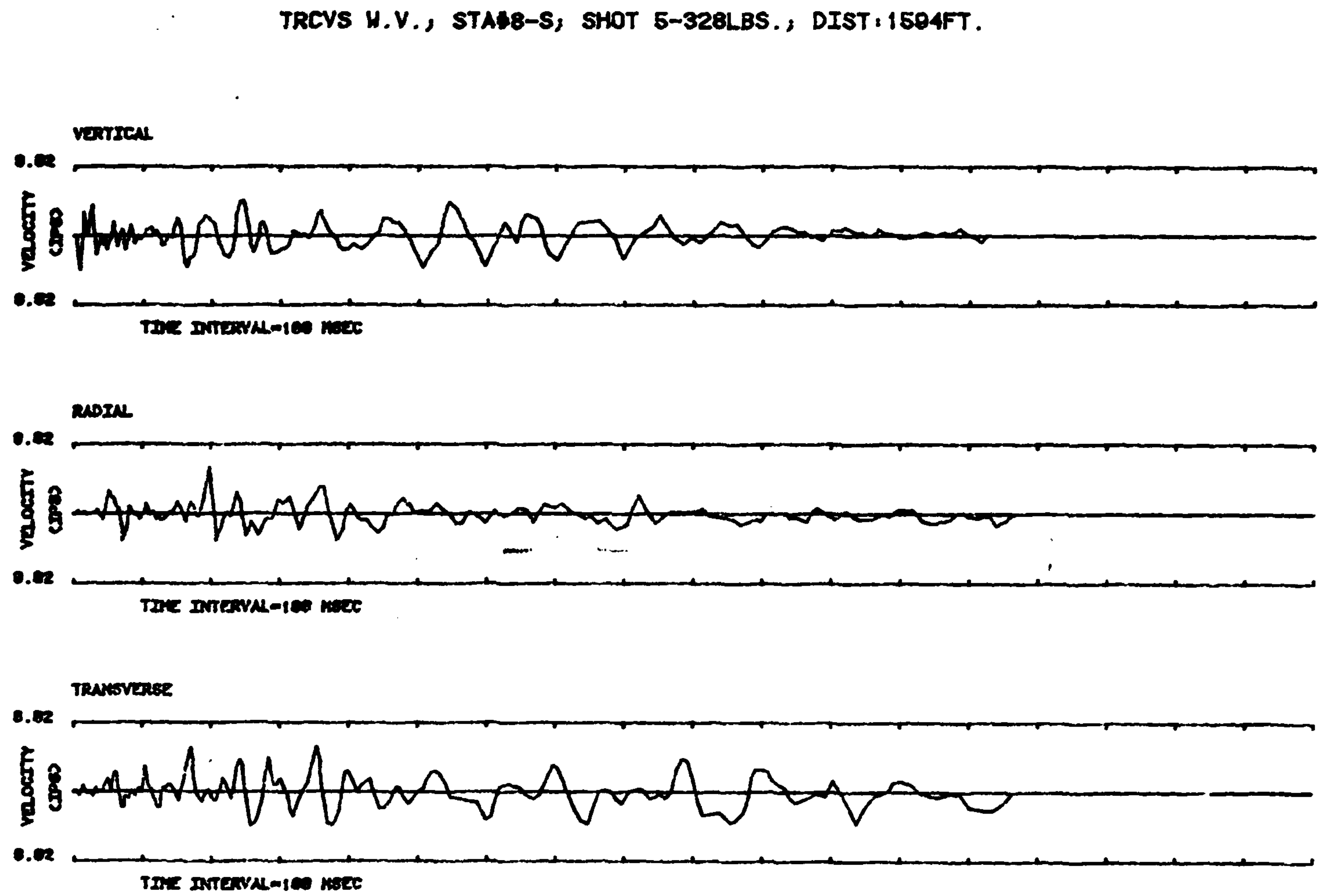

Figure E.13 Vertical, radial and transverse particle velocity measurements, gage canister in soil at 1594 ft slant distance.

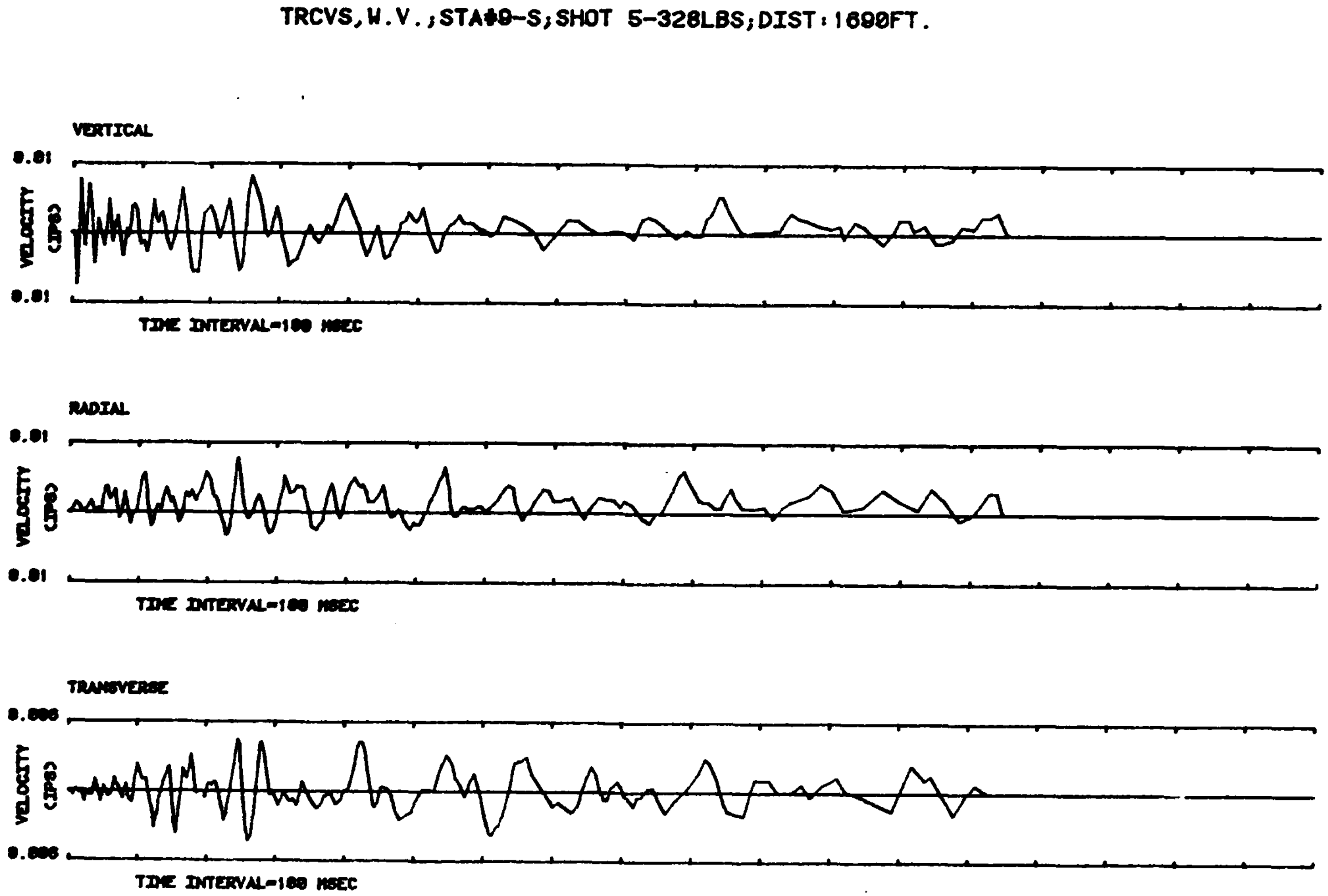

Figure E.14 Vertical, radial and transverse particle velocity measurements, gage canister in soil at 1690 ft slant distance.

TRCVS,W.V.;STA#14-F; SHOT#5-328LBS; DIST:2932FT.

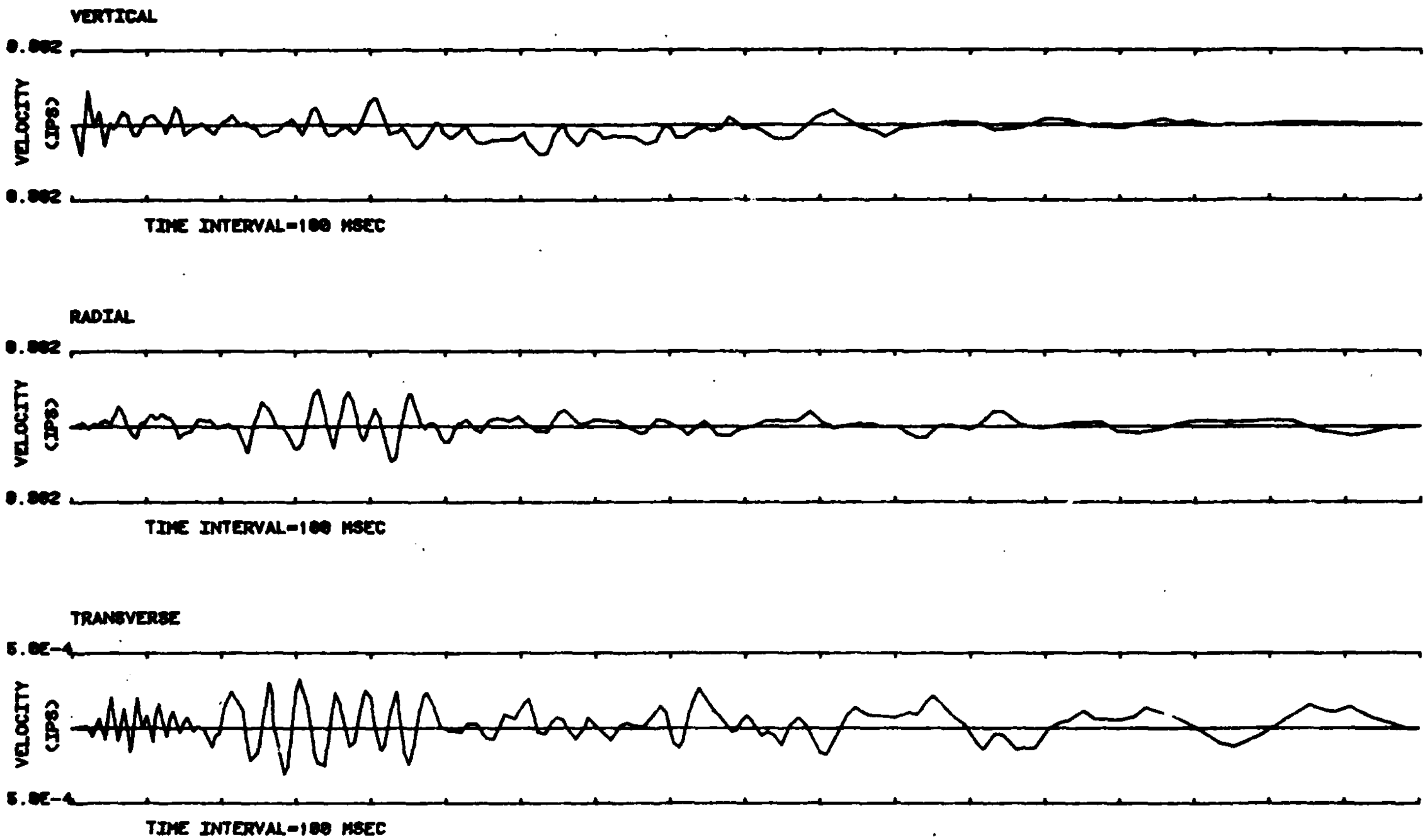

Figure E.15 Vertical, radial and transverse particle velocity measurements, gage canister on swimming pool deck (soil) at 2932 ft slant distance.

TRCVS,W.V.;STA#15-S; SHOT#5-328LBS; DIST:2971

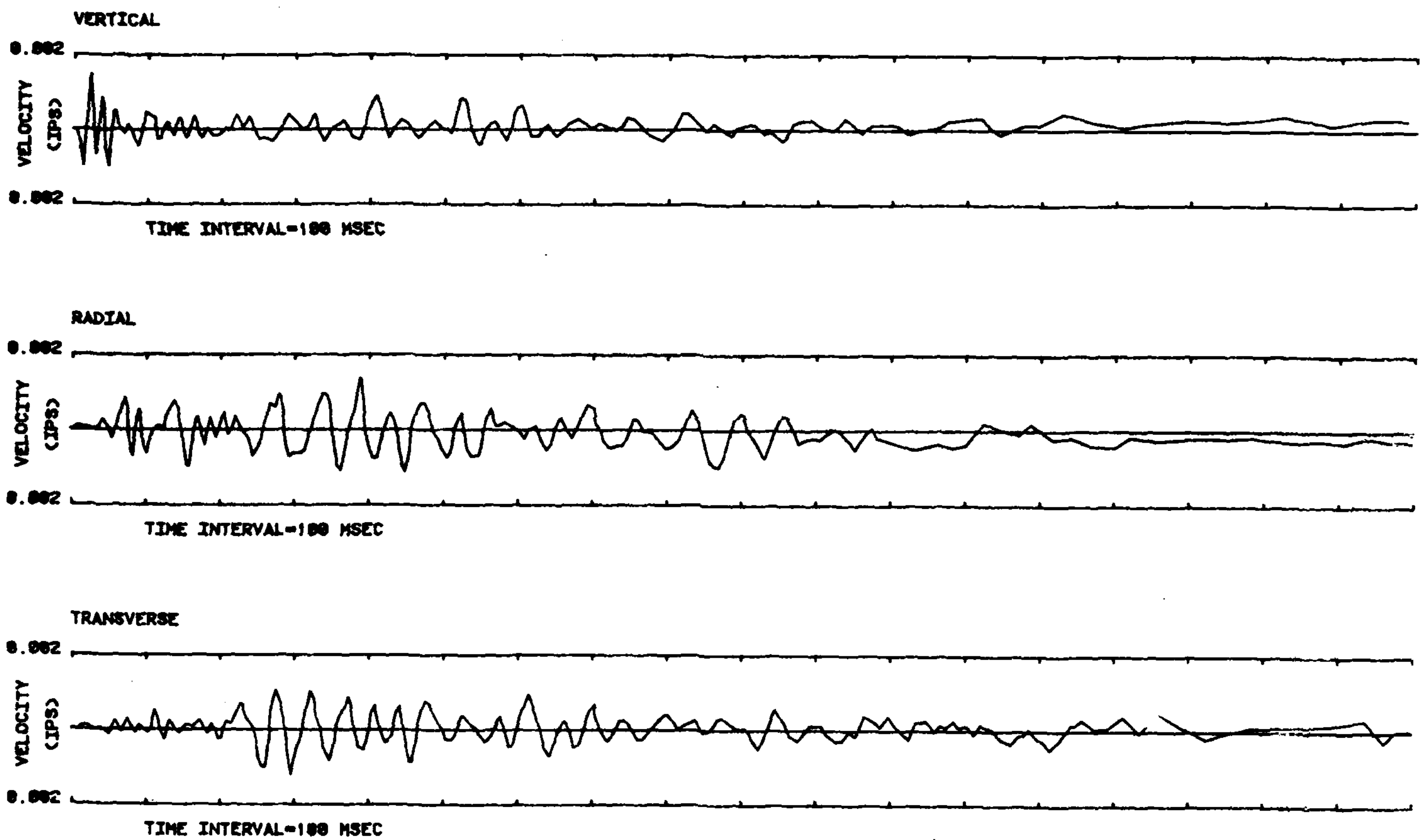

Figure E.16 Vertical, radial and transverse particle velocity measurements, gage canister in soil at 2971 ft slant distance.

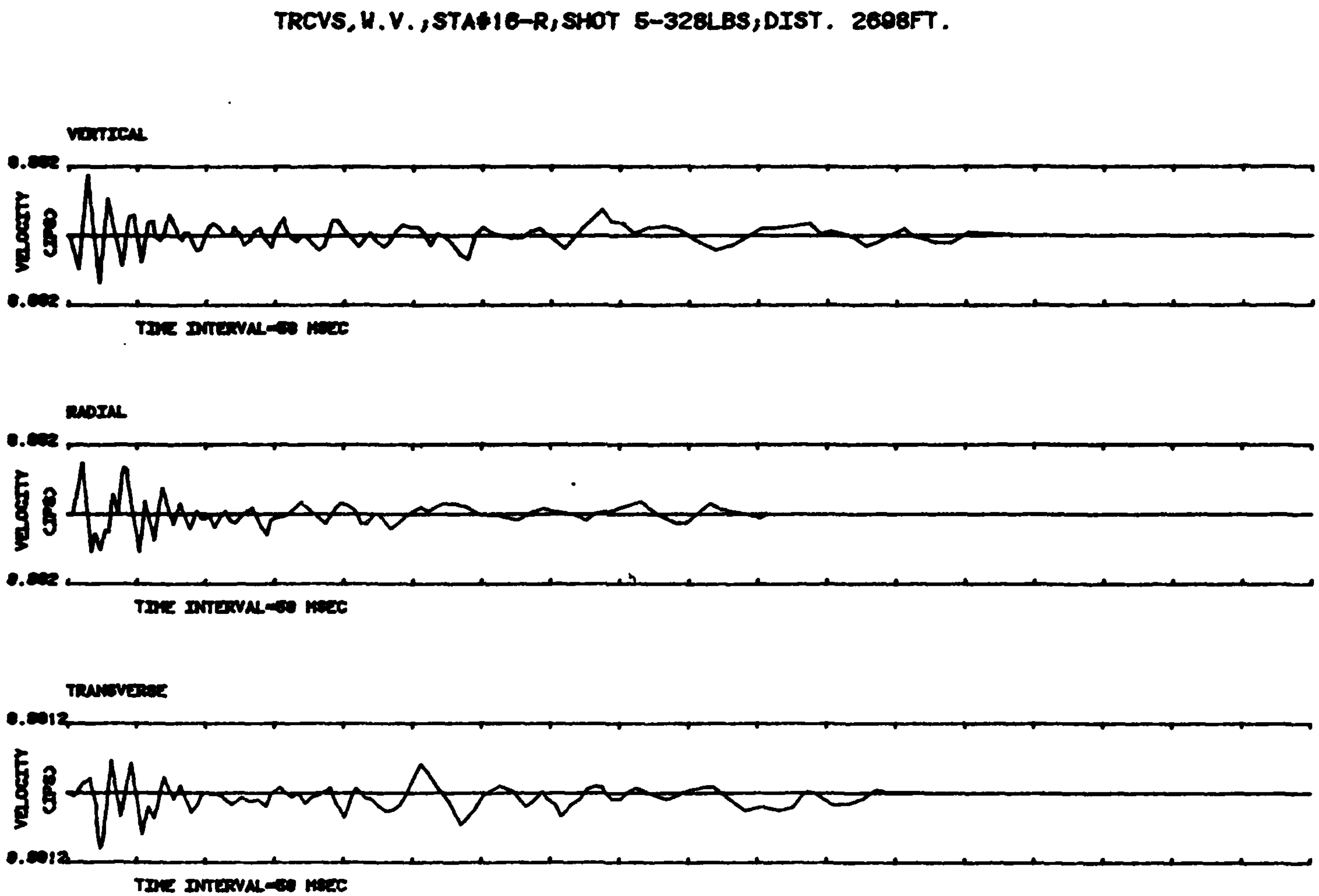

Figure E.17 Vertical, radial and transverse particle velocity measurements, gage canister on tunnel liner (rock) at 2698 ft slant distance.

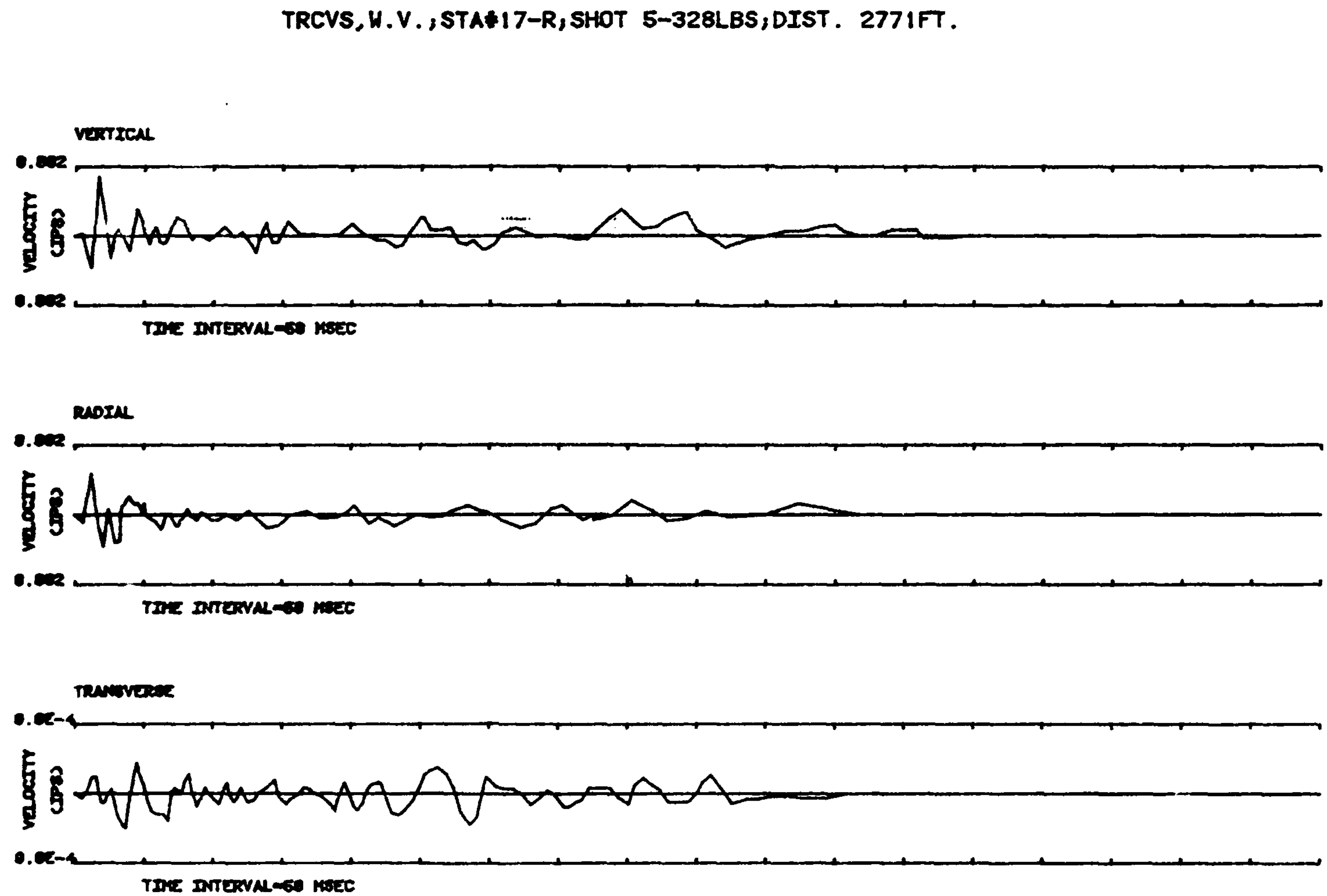

Figure E.18 Vertical, radial and transverse particle velocity measurements, gage canister in unlined tunnel (rock) at 2771 ft slant distance.

APPENDIX F

VEHICULAR INDUCED VIBRATIONS

RAILWAY AND HIGHWAY

Scope of Work

This Appendix describes efforts to establish background vibration levels near structures in the Matewan, WV, area in the vicinity of the proposed excavation. The work includes collection and analysis of railway and highway traffic induced vibration data near the proposed excavation. This portion of the overall study included: (1) measurement of train-generated vibration levels at nearby railroad tunnels and other selected sites; and (2) measurements of highway vehicle-induced motions at selected locations.

Experimental Plan

Vibrations induced by railway traffic passing through either or both railroad tunnels and over the Norfolk and Western (N&W) tracks through the Sprigg and Hatfield Bottom communities were recorded with triaxial seismic transducers. Monitoring stations were placed at the following locations indicated by number in the table below and in Figures F.1 through F.4:

Location No.	Location
1	Between railroad tracks outside N&W tunnels (east end)
2	Inside concrete lined N&W tunnels (east end)
3	Inside unlined N&W tunnel (east end)
4	Rock outcrop, Full Gospel Church, Hatfield Bottom
5	Edge of highway, Full Gospel Church, Hatfield Bottom
6	Edge of N&W right of way, Hatfield Bottom

Location No.	Location
7	Swimming pool, Williamson Country Club
8	Edge of road, Williamson Country Club
9A	Concrete slab, ground floor, Smith Towers, Hatfield Bottom
9B	Concrete slab, 3rd floor, Smith Towers, Hatfield Bottom
9C	Concrete slab, 6th floor, Smith Towers, Hatfield Bottom
9D	Concrete slab, 9th floor, Smith Towers, Hatfield Bottom

Instrumentation

Seismic transducers, signal conditioning and recording [illegible] used for the vibration study are described in the main [illegible] of this report.

Discussion of Results

Background vibration levels recorded [illegible] in Table F.1. In addition, station number, instrument [illegible], source description, estimated vehicle speed and [illegible] associated with peak vibration data are given. [illegible] to locations described in the Experimental Plan and identified [illegible] Figures F.1 through F.4.

Peak particle velocity [illegible] plotted versus [illegible] phone distance in Figure F.5. These are the peak velocity data without regard to orientation. Estimated data fits for loaded trains (coal and freight) are shown in this figure. The upper fit is derived from gages located on ballast or overburden. The lower line is from gages located on rock.

Our explanation for smaller motions recorded at stations founded on rock is attributed to road bed design. All track, even that inside the tunnels is set on crushed rock ballast. This material tends to dampen out the high frequencies and the impedance mismatch between the ballast and the underlying rock tends to further reduce peak particle velocities in the rock.

Measured train-induced peak particle velocity attenuated at $R^{-1.25}$ in overburden and R^{-1} in rock. This attenuation rate is approximately half that produced by point sources and approaches that found for line sources. A long train is, in effect, a line source with input from each unit of the train as it moves over the road bed.

Table F.1. Background Vibration Measurements, Tug Fork River, Big Bend Cutoff

Test No.	Instrument Location: Station	Instrument Location: Site Description	Vibration Source: Type	Vibration Source: Estimated Speed MPH	Peak Particle Velocity: Vertical IPS	Peak Particle Velocity: Radial IPS	Peak Particle Velocity: Transverse IPS	Estimated Frequency (Peak Velocity) HZ
1	1*	On ballast, 12' from track, 60' from unlined tunnel	Loaded coal train	45	0.200	0.120	0.320	50
2	1	On ballast, 54' from track, 60' from unlined tunnel	Loaded coal train	15	0.12	0.050	0.17	50
3	--	Unlined Tunnel						
4	1	On ballast, 54' from track, 60' from unlined tunnel	2 engines and caboose	25	0.008	0.020	0.010	
5	1	On ballast, 12' from track, 60' from unlined tunnel	Freight and coal train	Varied 15-30	0.100	0.150	0.160	50
	3	On rock, 4' from track, 5' into unlined tunnel			0.065	0.085	0.030	80-100
6	1	On ballast, 12' from track, 60' from unlined tunnel	Loaded coal train	15	0.120	0.170	0.200	50-60
	3	On rock, 4' from track, 5' into unlined tunnel			0.100	0.150	0.070	80-100
7	1	On ballast, 54' from track, 60' from unlined tunnel	Empty coal train	15	0.005	0.005	0.005	

(Continued)

* Double tunnels, this station was used to record vibrations from trains on either track

Sheet 1 of 5

Table F.1. (Continued)

Test No.	Instrument Location		Vibration Source		Peak Particle Velocity			Estimated Frequency (Peak Velocity) HZ
	Station	Site Description	Type	Estimated Speed MPH	Vertical IPS	Radial IPS	Transverse IPS	
8	1	On ballast, 54' from track, 60' from unlined tunnel	Loaded coal train	10	0.005	0.005	0.005	
		On rock, 54' from track,** 5' into unlined tunnel			0.015	0.065	0.015	60
9	3	On rock, 4' from track, 5' into unlined tunnel	Loaded coal train	15	0.040	0.050	0.060	80-100
10	3	On rock, 4' from track, 5' into unlined tunnel	Loaded coal train	40	0.065	0.080	0.070	100
	2	On tunnel liner, 60' from track,** 10' into tunnel			0.007	0.015	0.012	70-80
11	3	On rock, 70' from track,** 5' into unlined tunnel	3 engines	25	0.002	0.004	0.002	130
	2	On tunnel liner, 5' from track, 10' into tunnel			0.012	0.009	0.005	60

** Recording vibrations from train in other tunnel

Sheet 2 of 5

Table F.1. (Continued)

Test No.	Instrument Location: Station	Instrument Location: Site Description	Vibration Source: Type	Vibration Source: Estimated Speed MPH	Peak Particle Velocity: Vertical IPS	Peak Particle Velocity: Radial IPS	Peak Particle Velocity: Transverse IPS	Estimated Frequency (Peak Velocity) HZ
12	5	In overburden, 90' from track	Empty coal train	5	0.005	0.017	0.005	50-60
	4	On rock, 200' from track			0.001	0.002	0.001	70-80
13	5	In overburden, 90' from track	Loaded coal train	10	0.0052	0.015	0.004	50-60
	4	On rock, 200' from track			0.0008	0.0010	0.0012	80-100
14	5	In overburden, 90' from track	Freight and coal train	30	0.014	0.028	0.010	50-60
	4	On rock, 200' from track			0.002	0.014	0.0017	70-80
15	5	In overburden, 90' from track	Loaded coal train	20	0.016	0.032	0.017	50
	4	On rock, 200' from track			0.0016	0.0020	0.0024	70-80
16	6	In overburden, 20' from track	Loaded coal train	35	0.25	0.40	0.20	[illegible]

Sheet 3 of 5

Table F.1. (Continued)

Test No.	Instrument Location		Vibration Source		Peak Particle Velocity			Estimated Frequency (Peak Velocity)
	Station	Site Description	Type	Estimated Speed MPH	Vertical IPS	Radial IPS	Transverse IPS	HZ
18	8	In overburden, 55' from track	Loaded coal train	30	0.02	0.06	0.04	70
	7	On pool patio, 250' from track			0.008	0.004	0.006	10-30
19	8	In overburden 55' from track	Freight and coal train	15	0.01	0.03	0.03	40
	7	On pool patio, 250' from track			0.003	0.003	0.002	70
20	5	In overburden, 20' from WV 49 highway	Auto		0.006	0.005	0.005	30
21	5	In overburden, 20' from WV 49 highway	Auto		0.002	0.003	0.001	50
22	5	In overburden, 20' from WV 49 highway	2 coal trucks		0.009	0.014	0.007	25
	4	On rock, 140' from WV 49 highway			0.001	0.001	0.001	80
23	5	In overburden, 20' from WV 49 highway	Empty coal truck		0.006	0.010	0.004	40
24	5	In overburden, 20' from WV 49 highway	Loaded coal truck		0.006	0.006	0.004	25
	4	On rock, 140' from WV 49 highway			0.001	0.001	0.001	70

Sheet 4 of 5

Table F.1. (Concluded)

Test No.	Instrument Location: Station	Instrument Location: Site Description	Vibration Source: Type	Vibration Source: Estimated Speed MPH	Peak Particle Velocity: Vertical IPS	Peak Particle Velocity: Radial IPS	Peak Particle Velocity: Transverse IPS	Estimated Frequency (Peak Velocity) HZ
25	9A	Foundation Slab Smith Towers 300' from track	Loaded coal train	20	0.0005	0.0007	0.0005	20
	9B	3rd Floor Balcony Smith Towers 300' from track			0.0004	0.0007	0.0010	10
	9C	6th Floor Balcony Smith Towers 300' from track			0.0010	0.0012	0.0013	5
	9D	9th Floor Balcony Smith Towers 300' from track			0.0007	0.0010	0.0004	5

Sheet 5 of 5

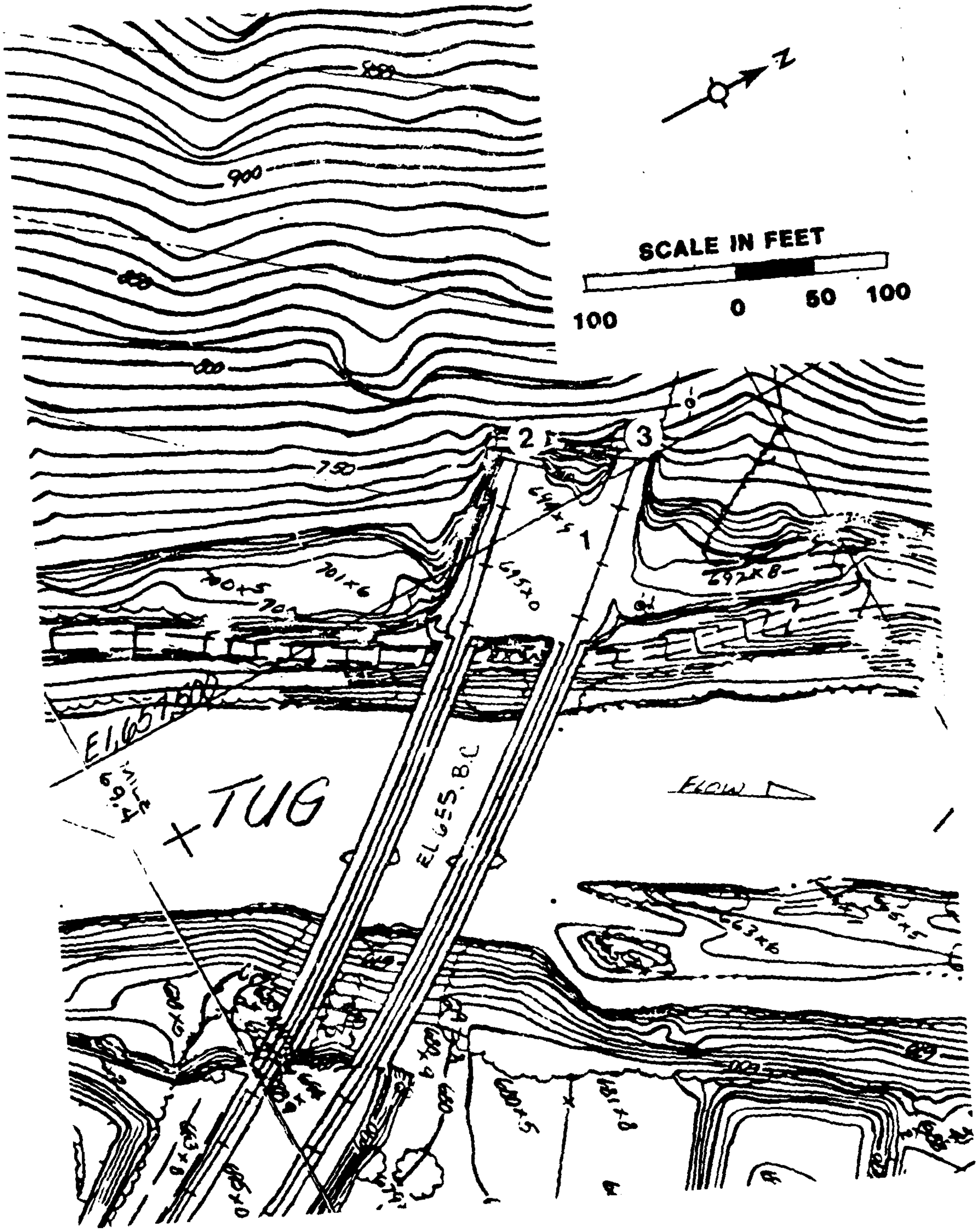

Figure F.1 Traffic induced vibration Monitoring Stations 1, 2, and 3; Norfolk and Western Railroad Tunnel (east end).

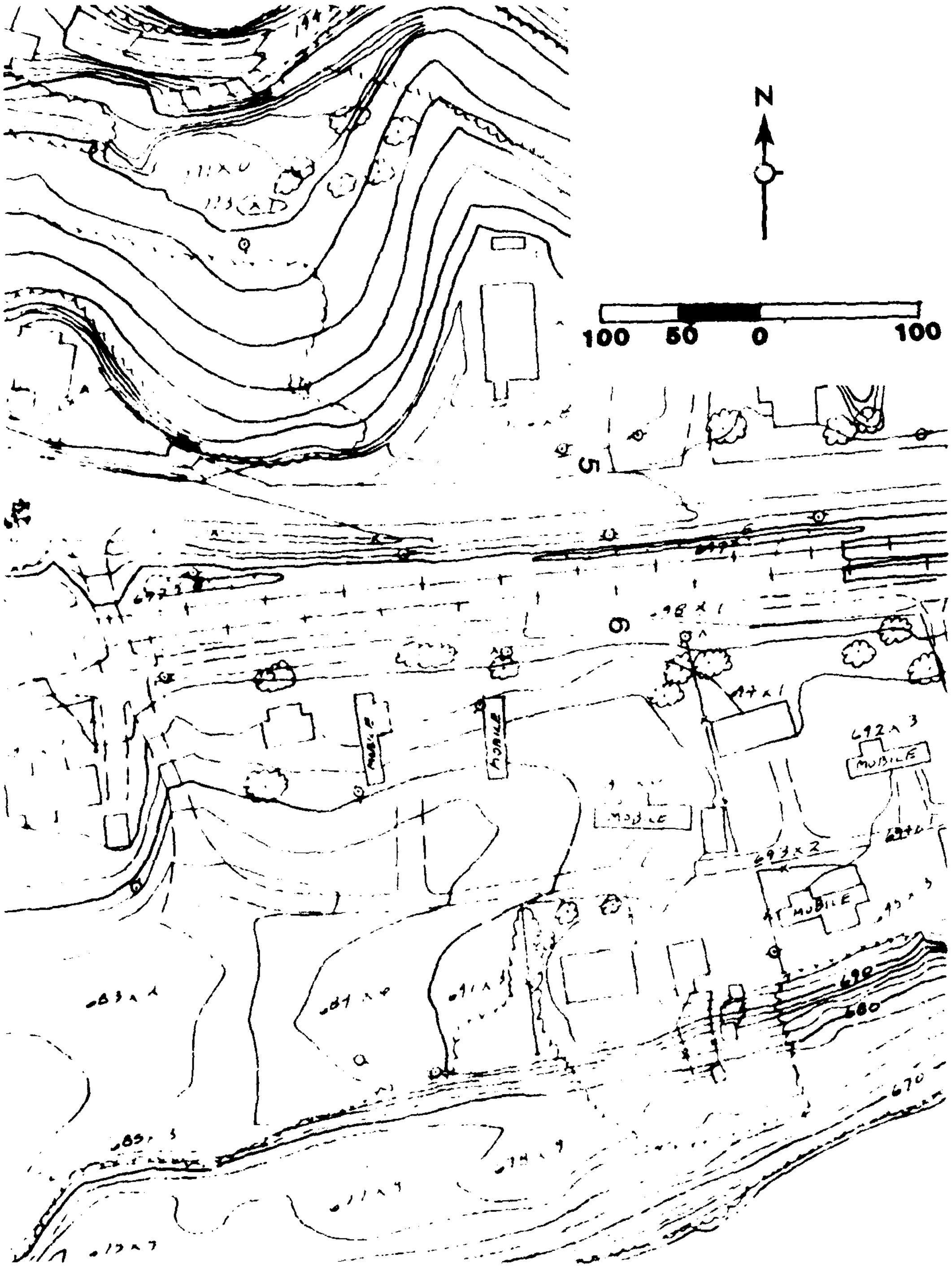

Figure F.2 Traffic induced vibration Monitoring Stations 4, 5 and 6; Hatfield Bottom.

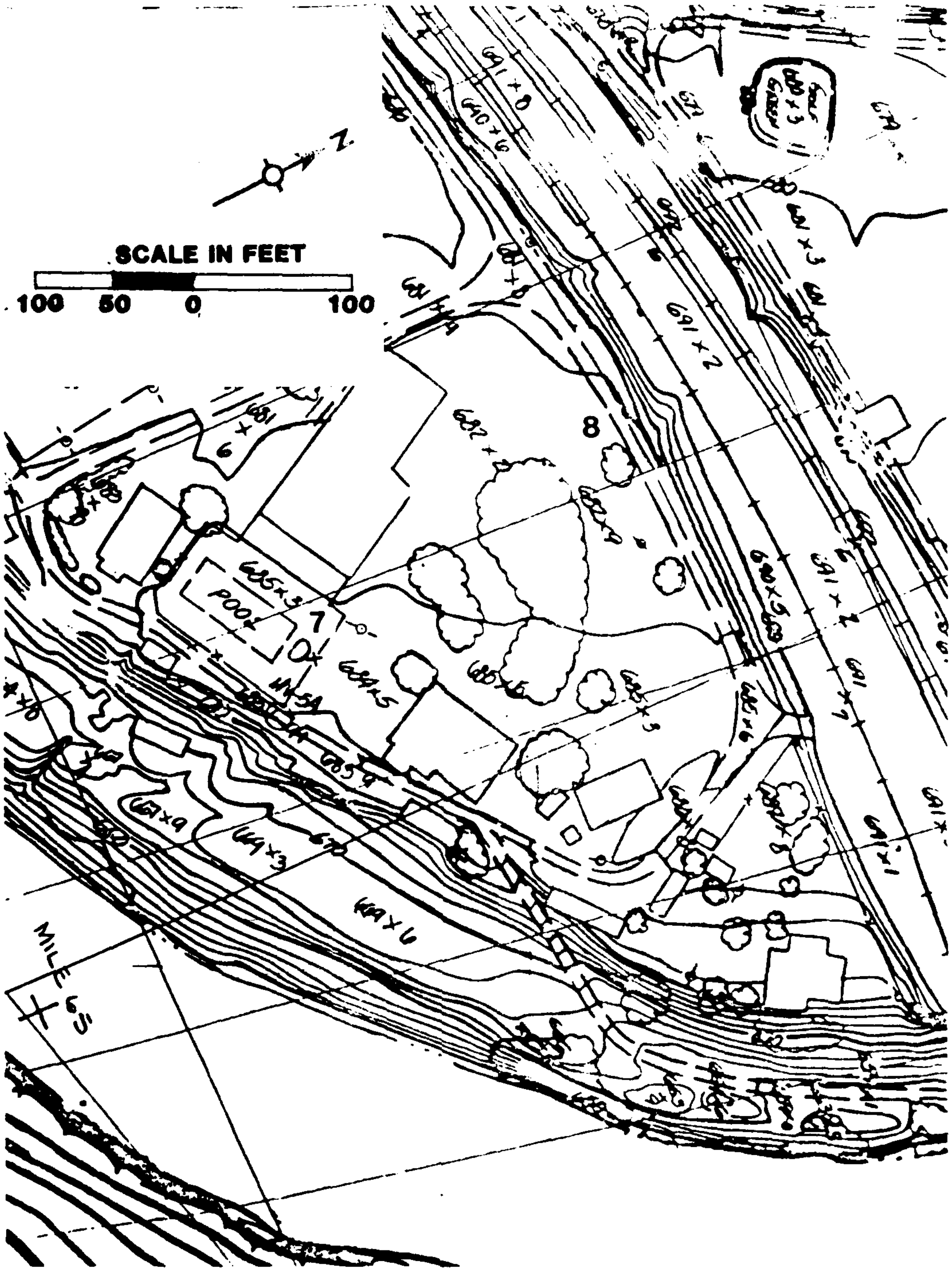

Figure F.3 Traffic induced vibration Monitoring Stations 7 and 8; Williamson Country Club.

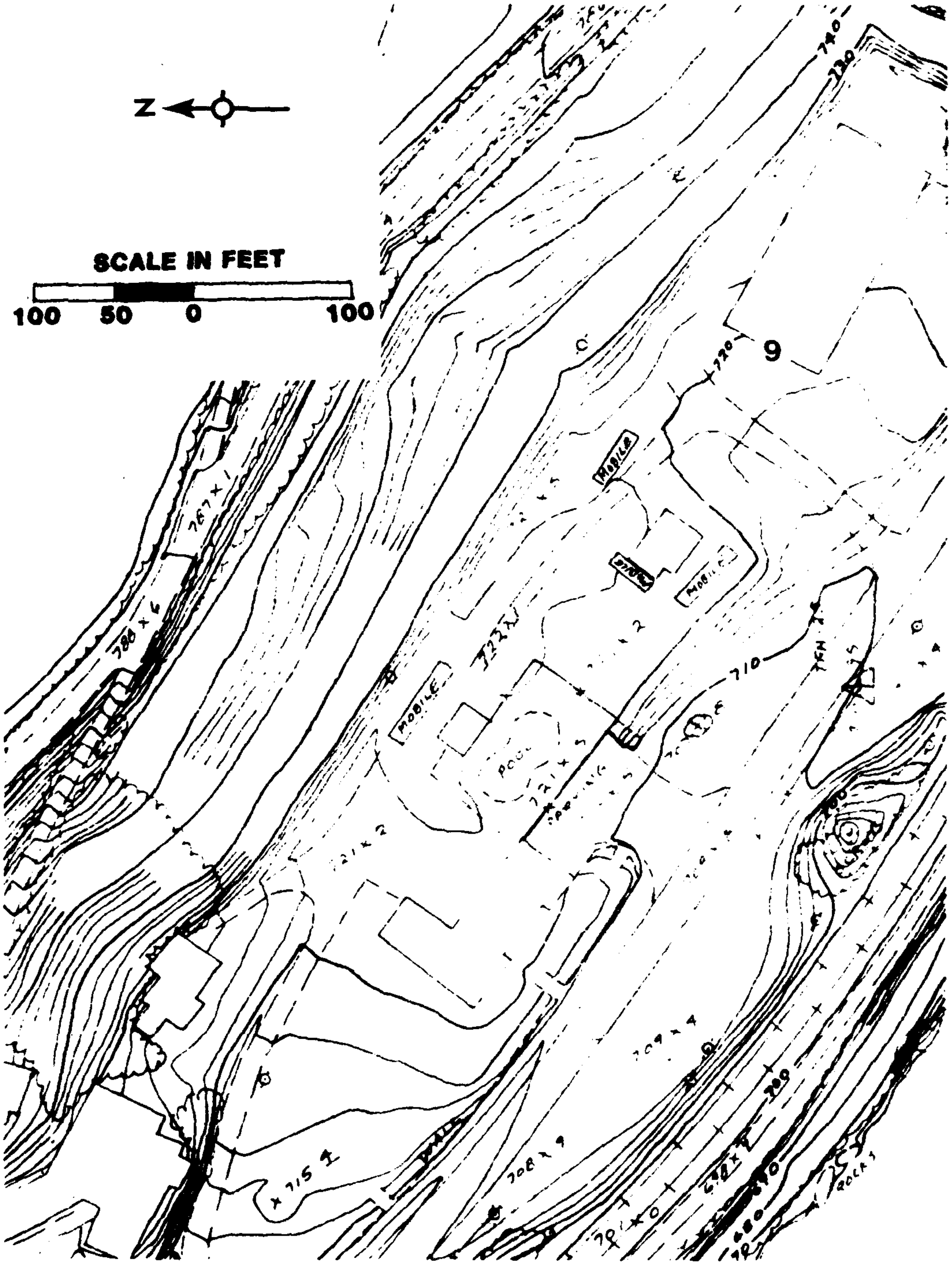

Figure F.4 Traffic induced vibration Monitoring Station 9; foundation, 3rd, 6th and 9th floor balconies, Smith Towers.

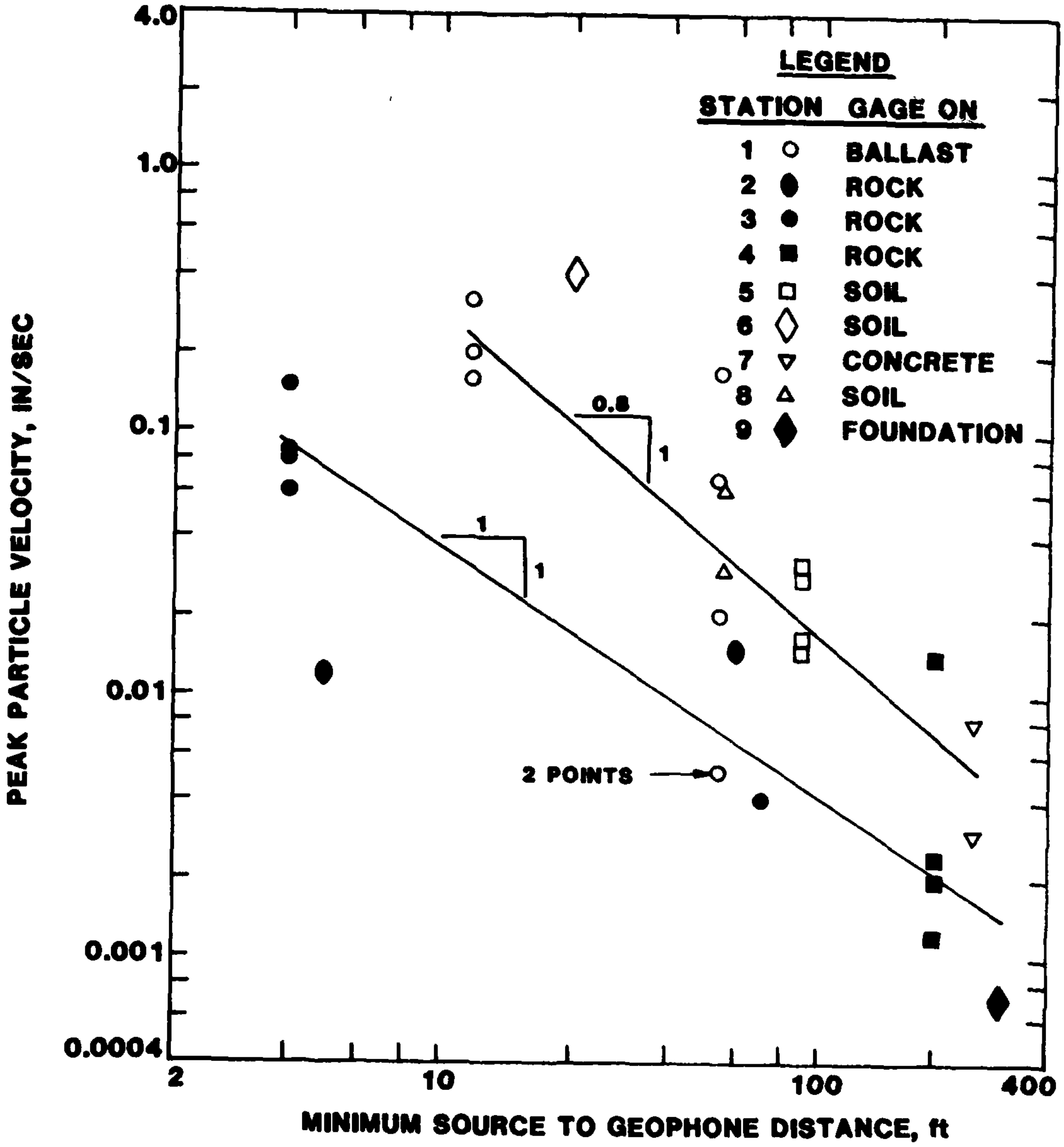

Figure F.5 Peak particle velocity versus minimum distance from Norfolk & Western railroad track.

In accordance with letter from DAEN-RDC, DAEN-ASI dated 22 July 1977, Subject: Facsimile Catalog Cards for Laboratory Technical Publications, a facsimile catalog card in Library of Congress MARC format is reproduced below.

Joachim, Charles E.
Tug Fork River Big Bend Cutoff Blast Monitoring Study / by Charles E. Joachim (Structures Laboratory, U.S. Army Engineer Waterways Experiment Station). -- Vicksburg, Miss. : The Station ; Springfield, Va. : available from NTIS, 1983.
155 p. : ill. ; 27 cm. -- (Miscellaneous paper ; SL-83-4)
Cover title.
"March 1983."
Final report.
"Prepared for U.S. Army Engineer District, Huntington."
Bibliography: p. 46.

1. Blast effect. 2. Blasting. 3. Explosions. 4. Seismic waves. 5. Vibration. I. United States. Army. Corps of Engineers. Huntington District. II. Title III. Series: Miscellaneous paper (U.S. Army Engineer

Joachim, Charles E.
Tug Fork River Big Bend Cutoff blast monitoring : ... 1983.
(Card 2)

Waterways Experiment Station) ; SL-83-4.
TA7.W34m no.SL-83-4

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